PB85-187656

Evaluating Rigid Foams for Construction and Repairing Mine Stoppings

MSA Research Corp., Evans City, PA

Prepared for

Bureau of Mines, Washington, DC

Oct 84

U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
NTIS

BuMines OFR 40-85

PB85-187656

A mining research contract report
OCTOBER 1984

EVALUATING RIGID FOAMS FOR CONSTRUCTION AND REPAIRING MINE STOPPINGS

Contract J0308006
MSA Research Corporation

Bureau of Mines Open File Report 40-85

BUREAU OF MINES
UNITED STATES DEPARTMENT OF THE INTERIOR

U.S. DEPARTMENT OF THE INTERIOR ★ BUREAU OF MINES ★ E PLURIBUS UNUM SAFETY EFFICIENCY MINERAL INDUSTRIES

U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. BuMines OFR 40-85	2.	3. Recipient's Accession No. PB85 187656/AS

4. Title and Subtitle

Evaluating Rigid Foams for Construction and Repairing Mine Stoppings

5. Report Date

Oct. 1984

6.

7. Author(s)

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8. Performing Organization Rept. No.

9. Performing Organization Name and Address

MSA Research Corp.
Evans City, PA 16033

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.

(C) J0308006

(G)

12. Sponsoring Organization Name and Address

Office of Assistant Director--Mining Research
Bureau of Mines
U.S. Department of the Interior
Washington, DC 20241

13. Type of Report & Period Covered

Contract research, 12/3/79--12/3/83

14.

15. Supplementary Notes

Approved for release April 5, 1985.

16. Abstract (Limit: 200 words)

Twenty-seven commercially available rigid foam materials were tested to delineate those most suitable for use as a sealant in underground mine stoppings. The rigid foam industry was surveyed for possible candidates based on published properties, cost, and application equipment. Using a process that recognized those properties of rigid foams that were important for use as mine stopping materials, laboratory tests reduced the initial listing to two. Flammability, air permeability, and mode of application comparisons played major roles in the selection process, with adhesion and cost comparisons being minor factors. Standard ASTM tests were employed where applicable.

17. Document Analysis a. Descriptors

Rigid foams
Urethane foams
Isocyanurate foams
Phenolic foams
Silicone foams
Flammability
Air permeability
Adhesion

b. Identifiers/Open-Ended Terms

Mine stoppings
Mine ventilation
Plastics, foam

c. COSATI Field/Group 08I

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Release unlimited by NTIS.	Unclassified	151
	20. Security Class (This Page) Unclassified	22. Price

(See ANSI–Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4–77) (Formerly NTIS–35) Department of Commerce

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FOREWORD

This report was prepared by MSA Research Corporation, a division of Mine Safety Appliances Company, Evans City, PA under USBM Contract number J0308006. The contract was initiated under the Minerals Health and Safety Technology Program. It was administered under the technical direction of Pittsburgh Research Center with Robert Timko acting as Technical Project Officer. Mr. Alan G. Bolton, Jr. was the contract administrator for the Bureau of Mines. This report is a summary of the work recently completed as a part of this contract during the period December 1979 to August 1983. This report was submitted by the authors on December 1983 and contains no patentable features.

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INTRODUCTION

Industrial workplace standards, implemented by the Mine Safety and Health Administration, designate the ventilation of underground mines to reduce methane concentrations and control dust levels. Distributing the enormous quantities of ventilating air required to maintain these standards in underground mines constitutes a continuous, expensive problem to the mining industry. Air leakage does not allow designed and needed quantities of air to get to the face where air is needed. Wasted energy in nonproductive air is very expensive.

Construction and maintenance of mine stoppings have been persistent problems throughout years of development and experience. Many energy intensive operations are necessary to obtain the required ventilation throughout the maze of shafts and passageways which comprise a mine. Stoppings must be erected regularly, as the face advances, to assure a flow of fresh air to the work face. Older stoppings must be repaired periodically, as subsidence and erosion take their toll. both new and old stoppings must be impermeable, or they will lose their function in directing the ventilating air into work areas.

Concrete blocks are almost universally employed in the construction of mine stoppings. Since all construction materials must be brought into the mine from the surface, this practice constitutes a significant logistics problem, which could be mitigated by the use of foamed materials.

When introduced to the mining industry years ago, urethane foams received wide acceptance as a partial answer to the stopping construction problems. Their impermeability, flexibility and adhesive properties were nearly ideal for coal mine stoppings. Unfortunately, the indiscriminate use of polyurethane, including poor spraying applications and the use of foams with poor flammability properties resulted in their involvement in mine fire situations. As a result, all foam materials have gained a reputation as a potential fire hazard in mine use.

Since the problems of constructing and maintaining stoppings universally influence the economics of mining operations, considerable interest has been generated for discovering alternative solutions to these problems.

This investigation has been designed to identify rigid, foamed materials which could be used to alleviate the problems involved in constructing and maintaining mine stoppings. It has been developed to fulfill a three-fold objective: tabulating, testing and selecting commercially available, foamed materials as alternatives for mine stoppings. This three-fold objective has been used in delineating a three-phase program; which is defined in the following manner:

Phase I - <u>List and Describe Rigid Foam Candidates;</u> consisting of a survey of the rigid foam industry for possible candidates for the program, tabulate available property, cost and application equipment data to aid in the selection of 30 foams for laboratory testing.

Phase II - <u>Lab Test of Rigid Foams</u>; selecting 30 foams for laboratory testing. Laboratory tests consist of comparing those properties that are most important for an in-mine stopping material, and subseqently selecting 2 for in-mine testing.

Phase III - <u>In-Mine Testing</u>; consists of the design, construction and testing of rigid foam stoppings in a cooperating mine.

This report describes the approach, mechanics and results of an investigation of the rigid, foamed materials industry in search of materials which would provide alternatives for constructing and maintaining mine stoppings.

APPROACH

In summary, the job consisted of selecting the two best rigid foam candidates for use in mine stopping construction and testing designs incorporating their use in actual mine conditions. To a considerable extent, the program success depended on the selection of the final candidates and demonstrating that the foam candidates would have practical applications underground.

The validity of the process for the selection of the two "best" rigid foam candidates for final testing depended on two parameters in Phase I. First, on an extensive industry survey to insure that all potential candidates were recognized. Second, on a screening and selection process that recognized those characteristics of rigid foams that are important for their use as mine stopping construction materials.

Data and information were sought on 22 generic types of foams from 94 manufacturers. From this information, 27 candidates representing 5 generic types of foam were selected for testing. The selection was based primary on reported flame spread data, mode of application and availability.

In the first test series, the 27 foams selected for testing were subjected to two laboratory-scale flame spread tests, ASTM E-162 and Callery's E-162-CCC-2. These test results were used to reduce the number of candidate foams to 15, using an arbitrary cut-off value, and discarding those candidates testing higher.

In the second test series, the 15 selected foams were subjected to water immersion tests. These tests determined the resistance of the foams to loss of fire retardancy, strength or closed cell content (related to air permeability) and their results were used to reduce the number of candidate foams to 10. Again, arbitrary cut-off values were employed.

In the final test series, the 10 remaining candidate foams were subjected to adhesion, air permeability, ignition, flame penetration and aging tests. All candidates "passed" these tests (i.e., met minimum requirements). Therefore, the flame spread data was used as the major criteria for selecting the "final 2." These "final 2" were then used to seal stoppings in several typical locations in a working mine.

SELECTION OF POTENTIAL FOAM CANDIDATES

FOAM SURVEY

A thorough examination of rigid, foamed materials was conducted in the first phase of this investigation. A preliminary goal was to contact representative manufacturers of all foamed materials and to compile data concerning each foam that would be sufficient to appraise the foam's adequacy for constructing and maintaining mine stoppings. During the initial search no material was eliminated off-hand from consideration.

Survey Mechanics

The survey of rigid foam manufacturers progressed through a series of five steps. Both telephone and letter communications were used to provide a clear definition of the objective of the survey and to compile data on potential products. The general mechanics and chronological order of the steps involved in this survey are outlined below.

1. Representative companies that market foamed materials were selected from manufacturers' indices, such as the Modern Plastics Encyclopedia and Thomas Register. Company names, addresses and telephone numbers were catalogued according to the generic type(s) of their product(s).

2. A general outline of the physical properties and other descriptive data required for evaluating candidate materials was prepared as a format for collecting data. Written inquiries included a cover letter which 1) explained the objective of this investigation, and 2) included brief summaries of the analytical approach and performance goals to be used in the evaluation of candidate materials.

3. Telephone contacts were made with the companies selected. Special efforts were taken to speak with individuals concerned with product research and development within the company. The individual's name, company products, pertinent data, experiences and opinions were noted on the data sheet for each contact. Address and/or telephone number changes were also verified at this time. References were noted for consideration and possible contact.

4. Data sheets were compiled for each company summarizing product information obtained from telephone contacts, product and safety data sheets. Where necessary, additional contacts were made for clarification.

5. Data for all potential candidates were collected into a composite tabulation of foam materials. This would be used in the comparison and selection of candidates during the second phase of the program.

This general sequence was followed in communications with 94 companies. Descriptions and responses were compiled in a chronological order to provide a means for following the progress of the survey of manufacturers. These original notations were expanded to include company names, addresses, telephone numbers, person(s) contacted and their responses.

Seventy-two companies representing 20 generic foam types, were initially selected to be contacted. These contacts provided further leads which culminated in communications with 22 additional manufacturers and added 2 more foam types. A list of the manufacturers contacted is given in Table 1. A more detailed list, including the manufacturer's address is given in Table A-1 of the Appendix. An alphabetical listing of the generic foams surveyed and the number of representative manufacturers contacted for each is presented in Table 2.

Data Solicited

The foam data solicited covered a wide range of properties. An ideal material for constructing and maintaining mine stoppings would be perceived as having the following general characteristics:

1. Good adhesive to the substrate
2. Low air permeability
3. Resistant to heat
4. Resistant to flame penetration
5. Resistant to surface flame spread
6. Resistant to ignition
7. Sufficiently flexible to prevent or reduce cracking
8. Reasonable structural strength
9. Maintenance of structural integrity following exposure to heat and fire
10. Maintenance of low air permeability following exposure to heat and fire
11. Resistant to deterioration over a period of 10-20 years.

TABLE 1 - Listing of manufacturers contacted

Generic Type	Company
ABS	Borg-Warner Corporation
Acetal	Celanese Plastic Materials Co.
Cellulose Acetate	American Polymers, Inc.
	Deltex Associates
	Eastman Chemical Products, Inc
Epoxy	Bacon Industries, Inc.
	Isochem Resins Company
	Shell Chemical Company
	Sika Chemical Company
	Emerson and Cumings, Inc.
	Kristal Kraft, Inc.
	Ren Plastics
Ionomer	Gilman Brothers Company
	Texas Urethanes
	Foam Systems Company
	Upjohn Company, CPR Division
Melamine-based	American Cyanamid
Phenolic	Schenectady Chemicals, Inc.
	Smithers Company
Phenylene Oxide-based	General Electric Company
Polyamide-imide	Amoco Chemicals Corporation
	Enplax Corporation
	Allied Chemical Corporation
	Celanese Plastic Materials Co.
Polybenzimidazole	Armstrong Cork Company
Polycarbonate	General Electric Company
Polyethylene	Dow Chemical Company
	Dynamit Nobel of America, Inc.
	Vantage Products
	Crest Foam, Inc.
	Northern Petrochemical Co.
	Rogers Foam Corporation
	United Minerals & Chemicals Corp.

Generic Type	Company
Polyimide	Ciba-Geigy Corporation
	Monsanto Company
Polypropylene	Northern Petrochemical Co.
	Vantage Products
	Sun Chemical Corporation
Polystyrene	Dow Chemical Company
	Northern Petrochemical Co.
Polyurethane	Atlas Minerals and Chemicals
	Chemetics Systems, Inc.
	Fomo Products, Inc.
	Furane Plastics Inc.
	BASF Wyandotte Corporation
	Cook Paint & Varnish Company
	Freeman Chemical Corporation
	Hastings Plastics Company
	Insta-Foam Products, Inc.
	Lankro Chemicals, Ltd.
	Kristal Kraft, Inc.
	M-R Plastics and Coatings
	Magnolia Plastics, Inc.
	Midwest Manufacturing Corp.
	Olin Chemical Corporation
	Pelron
	Fremont-Hayward
	Reichold Chemicals, Inc.
	Stepan Chemical Company
	Hoover Universal
	Texas Urethanes
	United Foam Corporation
	Upjohn Company, CPR Division
	Urethane Systems Corporation
	Utah Foam Products
	Witco Chemical Company
	Ashland Chemical Company

TABLE 1 - Listing of manufacturers contacted (cont'd)

Generic Type	Company
Polyurethane (continued)	W. R. Grace and Company
	Firestone Corporation
	Owens-Corning Company
	Tenneco Chemicals
	Mobay Chemical Company
	Cargill, Inc.
	Essex Chemical Corporation
	Callery Chemical Company
PVC	Diamond Shamrock Corporation
	Tenneco Chemicals
	Firestone Plastics Company
	Colorite Plastics Company
Silicate	Diamond Shamrock Company
	Caledonia Mining Company, Ltd.
	Southwest Research Institute
	Fiberglass Canada, Ltd.
Silicone	Dow-Corning Corporation
	General Electric Company
	Emerson and Cuming, Inc.

Generic Type	Company
Thermoplastic polyester	General Electric Company
	Celanese Plastic Material Co.
	Owens-Corning Fiberglass Corp.
Urea-formaldehyde	Arrowhead Plastics
	Ciba-Geigy Corporation
	Borden, Inc.
	Rapco Inc.
Natural Rubber Material (sprayable)	H. L. Blackford

TABLE 2 - Summary of survey contacts

Generic foam type	Initial selection	Manufacturers contacted	Candidate data received
ABS	1	1	1
Acetal	1	1	1
Cellulose-acetate	1	3	0
Epoxy	5	7	3
Ionomer	1	1	1
Isocyanurate	4	4	3
Melamine-based	0	1	0
Phenolic	2	2	1
Phenylene oxide-based	1	1	1
Polyamide-imide	2	4	3
Polybenzimidazole	1	1	0
Polycarbonate	1	1	1
Polyethylene	6	7	1
Polyimide	2	2	1
Polypropylene	2	3	0
Polystyrene	2	2	0
Polyurethane	29	35	34
PVC	2	4	0
Silicate	0	4	0
Silicone	3	3	2
Thermoplastic polyester	2	3	3
Urea-formaldehyde	4	4	1
Total	72	94	57

12. Resistant to loss of physical and fire resistant properties following exposure to heat or fire

13. Resistant to loss of physical and fire resistant properties following long-term exposure to ground water

14. Easily transported into mine

15. Easily and rapidly applied by relatively unskilled labor

16. Presents no unreasonable fire or toxic hazards as raw material, finished coating or during application

17. Be economical

18. Be easily repaired.

In compiling the data for each foam, data defining such areas as adhesion, combustibility, permeability, density, shelf life, safety hazards and strength were considered necessary for an objective evaluation of candidate materials. Data concerning application requirements and equipment, costs, maintenance and working life were considered beneficial, but of secondary importance in this initial tabulation of potential candidates. The data received for each material were tabulated in the format shown in Figure 1.

No commercial product was likely to have the desired combination of all 18 general characteristics outlined above. The survey, however, collected data within these 18 general areas to permit the subsequent selection during Phase II of foamed materials providing the best combinations of these characteristics.

Survey Response

Our initial communications with company representatives indicated that more than 100 products could be considered as candidates for constructing and maintaining mine stoppings. After considering the 18 general "ideal" characteristics or goals, many of the potential sealants were rejected. The survey finally compiled data for 62 products, which the manufacturers considered would be capable of partially fulfilling aforementioned goals.

Thirty-five manufacturers did not wish to participate in this survey. Reasons given were:

1. They had no product line that would fulfill the performance goals,

2. They had no desire to modify or develop their products for this use,

DATE: ____________

FIGURE 1 - Rigid foam survey format

COMPANY______________________ MSA FILE NO.____________

ADDRESS______________________ TELEPHONE____________

1. Person Completing Questionnaire____________

   Title____________

2. Foam Product (Name)____________

3. General Characteristics of Foam:

   a. Generic type of composition - ABS, Cellulose, Epoxy, Isocyanurate, Phenolic, etc. ____________

   b. Form - rigid, flexible ____________

   c. Shelf life ____________

   d. Density ____________

   e. Closed cell (%) ____________

   f. Adhesion to - wood, rock, coal, metal, etc. ____________

   g. Foam properties:

      Thermal - 1) Maximum/Minimum Service Temperature ____________

      - 2) Flame Spread ________ Test Designation No.________

      - 3) Smoke Developed ________ Test Designation No.________

      - 4) Oxygen Index ________

      Mechanical- 1) Compressive Strength ____________

      - 2) Tensile Strength ____________

4. General Foam Preparation Procedures:

   a. Processing method - (pour, froth, spray)____________

   b. Mixing conditions: time________ temperature________

   c. Substrate conditions: wet ________ dry________

   d. Cure conditions: time________ temperature________

   e. Viscosity of components: 1)________ 2)________ 3)________

   f. Flash point of components: 1)________ 2)________ 3)________

   g. Shelf life of components: 1)________ 2)________ 3)________

   h. Type and costs for application equipment____________

5. Environmental Factors and Considerations:

   a. Water absorption

   b. Water vapor transmission (permeability)

   c. Effect of water on: fire resistance________ permeability________

   d. Effect of aging on: fire resistance________ permeability________

3. They had negative attitudes or opinions concerning the intended use of their product(s),

4. They lacked interest, or

5. They expressed concern or fear based upon previous exposure to the misunderstandings and harrassment that occurred after the Sunshine mine disaster.

Fortunately, most of the manufacturers responded quickly and thoroughly to the inquiry. Their gracious and prompt response made the survey significantly more meaningful.

DISCUSSION OF SURVEY DATA

Data were compiled on 62 candidate foams. The list of candidates, by manufacturer and product designation, is shown in Table 3. The complete data compilation is included in the Appendix as Table A-2.

The candidate list includes 10 foams for which the manufacturer declined to respond to our survey. The data for these foams were obtained from the reference Desk-Top Data Bank For Foams[1], an essentially complete reference work containing data on about 900 foams. Besides providing a check on the thoroughness of our survey, the reference work allowed us to check the data received from manufacturers of many of our selected foams.

Attempts were made to obtain information on all of the 22 generic types of foam shown in Table 2. However, the final compilation lists only 15 generic types, including nitrile/vinyl blend, which was not included in the original listing. Of the 62 foams identified as being potential candidates, 35 were polyurethane, while 27 were from the remaining 14 generic categories. The heavy emphasis on polyurethane reflects the similarity of the properties of this foam type to the properties of the "ideal" sealant, and also the popularity of this foam type for general commercial use. Manufacturers of the following generic types deemed them unsuitable for use in stoppings:

a. cellulose acetate
b. polyimide
c. polypropylene
d. polystyrene
e. PVC (polyvinyl chloride

while no usable information could be obtained on the following:

1Desk-Top Data Bank For Foam, The international Plastics Selector, Cordura Publications, Inc., ISBN 0-8470-6028-4 (1978).

Table 3 - Listing of potential candidates

Generic Type	Manufacturer	Product Identity
ABS	Borg-Warner Corporation	Cyclolax FBK
Acetal	Celanese Plastic	Celcon M90
Amide-imide	Allied Chemical	Capron XPN 1173
	Celanese Plastics Co.	Nylon 1503
Epoxy	Ren Plastics	RP 1774
Ionomer	Gilman Brothers	Suryln Softlite
Nitrile/vinyl	Armstrong Cork	Armaflex 11
Phenol/formal-	Reichhold Ltd.	Phenolite 1B322/1D644
dehyde	Schenectady Chemicals	HRJ-913
Phenylene Oxide	General Electric	Noryl FN215
Polycarbonate	General Electric	Lexan 1800
Polyethylene	Dow Chemical Company	Ethafoam 222
Urea/formaldehyde	Ciba-Geigy	Aerolite SPE
	Raperswill	Rapco-Foam
Silicones	Dow-Corning	3-654BRTV
	Emerson & Cuming	Eccofoam SIL
	General Electric	RTV 6428
	General Electric	RTV 7403
	General Electric	RTV 850
Thermoplastic	Celanese Plastics Co.	Celanex 3210
Polyesthers	Celanese Plastics Co.	Celanex 3310
	General Electric	Valox FV-600
Isocyanurates	Chemetric Systems	CS1 9575
	Foam Systems	FSC 55
	Insta-Foam Products	ICU Kit
	Texas Urethanes	Texthane 333
	Upjohn Co.	Isonate CPR 425
Urethanes	Ashland Chemical	Phenolic Urethane
	Atlas Minerals & Chemicals	Urefoam R-02
	Atlas Minerals & Chemicals	Urefoam R-07
	BASF Wyandotte	Pluragard S-602
	CCC/MSA	Rigimix E/F
	CCC/MSA	X-156
	Chemetics Systems	CS1 8420
	Chemetics Systems	CS1 9120
	Chemetics Systems	CS1 9152
	Cook Paint and Varnish Co.	Coro-Foam G 325
	Cook Paint and Varnish Co.	Coro-Foam 440
	Emerson & Cuming	Eccooam FPH-FR
	Foam Systems Co.	FS 24
	Foam Systems Co.	FS 25
	Foam Systems Co.	FS 234
	Fomo Products, Inc.	Fomospray

Table 3 - Listing of potential candidates (cont'd)

Generic Type	Manufacturer	Product Identity
Urethanes (continued)	Freeman Chemical	Chempol 30-212/30-2038
	Hoover Universal	RU 6100
	Insta-Foam Products, Inc.	FS-75 Kit
	Isochem Resins Co.	9 R 2
	Olin Corp.	Autofroth 7415-02
	Olin Corp.	Polysystem 7622-02
	Olin Corp.	Polysystem 7613-02
	Polymir	FMS-20
	Texas Urethanes	Texthane 220-20
	United Foam	UFC-115
	United Foam	UFC-250
	Upjohn Co.	Isonate CPR 468
	Urethane Systems	USC 230
	Utah Foam Products Co.	FMS 20
	Witco Chemical	SS-0640
	Witco Chemical	SS-0501
	Witco Chemical	SS-0119A/SS-0120B
	W. R. Grace	Hypol

f. melamine based
g. polybenzimidazole
h. silicate

The companies that were involved with silicate foams 10 years ago have all dropped their programs, probably because of lack of acceptance by the market.

Some of the other generic candidates deserve general comments:

- Urea/formaldehyde forms have been marketed widely during the past few years. In the last few months, several manufacturers have taken them off the market; this includes the Ciba-Geigy foam shown in Table 3 (removed 1 April 1980). Thus, this type of foam will not be available in the near future. The reason for the removal of these urea/formaldehyde forms is the reputed release of formaldehyde vapors when the foam is not handled or made properly.

- Phenol/formaldehyde foams have been around for over 10 years, but they have never become very popular. The foaming reaction is catalyzed by strong acids. This causes corrosion problems which are unacceptable in many applications. Nevertheless, there is now a moderate resurgence of interest in these foams.

- Epoxy foams that could be sprayed were marketed by shell 10-15 years ago, but they were dropped. Epoxy foams offered advantages over urethane foams but had several disadvantages, including higher cost.

FOAM TESTING

CANDIDATE FOAM SELECTION

The information obtained during the foam survey was studied to select approximately 30 foams for testing. The foams were divided into two groups, "potential candidates" and "rejected", based on their apparent suitability for use in constructing and repairing mine stoppings.

Potential Candidates

The "potential candidate" group, shown in Table 4, totalled 36 foams and consisted of the 27 candidates listed as "yes", and the 9 listed as "maybe" for the assessment "suitability for mine use" in Table A-2 of the Appendix. Foams were listed as "maybe" when the mode of application, strength of the foam, and/or open-celled structure of the foam might create special problems. Most of the "maybe" assessments were for non-urethane foam types. The one "maybe" assessment for the urethane category was for Hypol, a solids-loaded, semi-rigid foam from W.R. Grace, developed as a fire-resistance mattress material for institutions.

The foams listed as potential candidates all met both the combustibility and mode of application criteria. The flame spread ratings were <30 and they could be applied by one of the four common techniques: (1) spraying, (2) frothing, (3) pouring, or (4) with adhesives. Although all techniques are possible for general construction, there are definite preferences for in-mine application. In order of preferance:

<u>Spraying</u> is probably the easiest and most satisfactory method of applying foam in mines. Several manufacturers offer equipment for spraying foam iin the $8,000 to $10,000 range. such equipment does require systematic maintenance by trained personnel for satisfactory results. For maximum safety the operators should be properly trained.

<u>Frothing</u> is a close second choice to spraying. Some frothing systems, such as Items 102 and 126 in Table 6, are completely self-contained systems and can be used by people with a minimum of training. Other froth systems require equipment and training similar to that used in spraying.

<u>Pouring</u> is a common way of dispensing foams, but the viscosity of the materials and the rapidity of foaming is not always compatible with mine use. Each system had to be evaluated on its own merits while preparing the samples for testing. The equipment used for pouring may be similar to that used for spraying or it may be more sophisticated and require skilled workers.

TABLE 4

Potential foam candidates

No	Generic type	Foam supplier	Product identity	Mode of application	Combustibility Smoke	Combustibility Rating	Combustibility Method	Maximum Service temp °F	Density pcf	% Closed cell
101	Isocyanurate	Chemetics Systems	CSI 9575	Spray	150	25	E84	ND	2.5	94
102	"	Insta-Foam Products	ICU Kit	Froth	400	25	E84	300	2.5	>90
103	"	Texas Urethanes	Texthane 333	Froth	ND	25	E84	ND	2.1	94
104	"	Upjohn Company	Isonate CPR 425	Spray	400	25	E84	ND	2	90
105	Nitrile/vinyl	Armstrong Cork	Armaflex II	Glue	100/150	25	E84	220	6	High
106	Phenol/formaldehyde	Reichhold Ltd.	Phenolite 1B322/10644	Spray	0	5	E84	400	3	50
107	Silicone	Dow Corning	3-6548 RTV	Pour	ND	20	E84	High	17	>50
108	"	General Electric	RTV 6428	Pour	54	13	E84	High	85	ND
109	"	General Electric	RTV 7403	Pour	ND	25	E84	High	80	ND
110	"	General Electric	RTV 850	Pour	204	21	E84	High	20-25	95
111	Urea/formaldehyde	Ciba-Geigy	Aerolite SPE	Pour/Spray	125/200	20	E84	200	1	1
112	"	Raperswill	Rapco Foam	Pour/Spray	0/5	25	E84	ND	0.7	ND
113	Urethane	Ashland Chemical	Phenolic Urethane	Pour	140	20	E84	225	2	90
114	"	BASF Wyandotte	Pluragard S-602	Spray	350	25	E84	250	2	ND
115	"	CCC/MSA	Rigimix E/F	Spray	350	25	E84	250	2	>90
116	"	CCC/MSA	X-156	Spray	150	20	E84	250	2	>90
117	"	Chemetics Systems	CSI 8420	Froth	190	20	E84	ND	2	94
118	"	Chemetics Systems	CSI 9120	Spray	110	20	E84	ND	2	96
119	"	Chemetics Systems	CSI 9152	Spray	305	20	E84	ND	2	95
120	"	Cook Paint & Varnish	Coro-Foam G325	Spray	185	30	E84	ND	2	>90
121	"	Cook Paint & Varnish	Coro-Foam 440	Froth	75	25	E84	ND	2	>90
122	"	Foam Systems Company	FS 24	Spray	115/450	25	E84	ND	2	'90
123	"	Foam Systems Company	FS 25	Spray	130/500	25-30	E84	ND	2	90
124	"	Foam Systems Company	FS 234	Spray	200/500	25	E84	ND	2.2	90
125	"	Freeman Chemical	Chempol 30-212/30-2038	Spray	250/350	25	E84	ND	2	94
126	"	Olin Corporation	Autofroth 7415-02	Froth	250	20	E84	ND	2.1	ND
127	"	Olin Corporation	Polysystem 7622-02	Spray	200	25	E84	ND	2.2	ND
128	"	Polymir	FMS-20	Spray	150	20	E84	ND	2.1	95
129	"	Texas Urethanes	Texthane 220-20	Spray	175	25	E84	ND	2	95
130	"	United Foam	UFS-250	Spray	ND	25	E84	ND	2	ND
131	"	Upjohn Company	Isonate CPR 468	Spray	350	25	E84	ND	2	92
132	"	Urethane Systems	USC 230	Spray	500	25	E84	ND	2	95
133	"	Utah Foam Products Co.	FMS 20	Spray	300	25	E84	ND	2	94
134	"	Witco Chemical	SS-0640	Spray	450	25	E84	ND	2	>90
135	"	Witco Chemical	SS-0501	Spray	<450	25	E84	ND	2	>90
136	"	W. R. Grace	Hypol	Pour/Spray	ND	<25	E84	ND	10-15	Low

Note: ND = No data

Adhesives can also be used to affix foam to the substrate, but then the adhesive must also be evaluated. Using adhesives can be slow or fairly fast, but the foam must be carried into the mine and carefully attached. This is probably the least satisfactory mode of application.

Rejected Candidates

Those foams rejected for use in stoppings are shown in Table 5, along with the key reasons for rejection.

The primary causes for rejection were based on the mode of application and the combustibility of the foams. The key criteria used for rejection were:

a. Flame spread higher than 30 as measured by ASTM E84.

b. Flame spread higher than 25 as measured by ASTM E162.

c. Combustibility greater than V0 by UL 94.

d. Self-extinguishing by ASTM D1692.

e. Pass by MV 302.

f. No data (ND) on combustibility.

g. Prepared by molding or extrusion.

Secondary consideration was also given to the maximum service temperature, foam density and the closed cell content. These criteria were as follows:

h. Maximum service temperature below 200°F.

i. Densities greater than 30 lbs/ft^3.

j. Closed cell content of less than 80%.

Failure to meet the secondary criteria were not sufficient cause for rejection, but served as a warning sign for careful scrutiny.

A total of 26 candidates were rejected and were excluded from further consideration in the selection process. Fourteen failed because of their mode of application -- they must be molded or extruded; 20 failed because of combustibility; and 9 failed for both reasons. Table 6 summarizes the reasons for rejection for candidates listed in Table 5. Item 215 (isocyanurate) was an exception to the above categories. It failed because the substrate must be heated to at least 100°F prior to

TABLE 5

Foams rejected

No	Generic type	Foam supplier	Product identity	Mode of app'l	Combustibility rating	method	Maximum Service temp °F	Density pcf	% Closed cell
201	ABS	Borg-Warner Corporation	Cycolac FBK	Mold	V0/5V	UL94	170	45	ND
202	Acetal	Celanese Plastics Company	Celesn M90	Mold	Burning	UL94	307	62	ND
203	Amide/imide	Allied Chemical	Capron XPN 1173	Mold	ND		300	55	ND
204	"	Celanese Plastics Company	Nylon 1503	Mold	Burning	UL94	490	60	100
205	Epoxy	Ren Plastics	RP 1774	Pour	ND		128	15	ND
206	Ionomer	Gilman Bros.	Surlyn Softlite	Mold	Pass	MV302	160	3	ND
207	Phenolic	Schnectady Chemical	HRJ-913	Pour	ND		ND	3	ND
208	Phenylene oxide	General Electric	Noryl FN 215	Mold	110	E162	180	50	ND
209	Polycarbonate	General Electric	Lexan 1800	Mold	18	E162	270	60	ND
210	Polyethylene	Dow Chemical	Ethafoam 222	Mold	Burning		180	3	100
211	Silicone	Emerson & Cuming	Eccofoam SIL	Pour	ND		400	20	Closed
212	Thermoplastic	Celanese Plastics Company	Celanex 3210	Mold	V0	UL94	417	68	ND
213	polyester	Celanese Plastics Company	Celanex 3310	Mold	V0	UL94	424	72	ND
214	"	General Electric	Valox FV-600	Mold	V0	UL94	340	70	ND
215	Isocyanurate	Foam Systems	FSC 55	Spray	25	E84	ND	2	93
216	Urethane	Atlas Minerals & Chem.	Urefoam R-02	Pour	ND		170	2	ND
217	"	Atlas Minerals & Chem.	Urefoam R-07	Pour	ND		170	7	ND
218	"	Emerson & Cuming	Eccofoam FPH-FR	Spray	SE	D1692	275	3	ND
219	"	Fomo Products, Inc.	Fomospray	Froth	SE	D1692	ND	1.5	70
220	"	Hoover Universal	RU 6100	Spray	<75	E84	ND	2	90
221	"	Insta-Foam Products, Inc.	FS-75 Kit	Froth	65	E84	250	2	90
222	"	Isochem Resins Company	9R2	Pour	SE	D1692	165	2	ND
223	"	Olin Corporation	Polysystem 7613-02	Spray	64	E84	ND	2	ND
224	"	United Foam	UFC-115	Spray	<75	E84	ND	2	95
225	"	Witco Chemical Company	SS-0119A/SS-0120B	Spray	<75	E84	ND	2	>90
226	"	Witco Chemical Company	SS-0715	Spray	<75	E84	ND	2	>90

Note: ND = No data

TABLE 6
Causes for rejection of materials
listed in Table 5

Item no	Mode of application	Combustibility	Service temp, max	Density pcf	Closed cell
201	Fail	Pass	Fail	Fail	ND
202	Fail	Fail	Pass	Fail	ND
203	Fail	Fail	Pass	Fail	ND
204	Fail	Fail	Pass	Fail	Pass
205	Fail	Fail	Fail	Pass	ND
206	Fail	Fail	Fail	Pass	ND
207	Pass	Fail	Fail	Pass	ND
208	Fail	Fail	Fail	Fail	ND
209	Fail	Pass	Pass	Fail	ND
210	Fail	Fail	Fail	Pass	Pass
211	Pass	Fail	Pass	Pass	Pass
212	Fail	Pass	Pass	Fail	ND
213	Fail	Pass	Pass	Fail	ND
214	Fail	Pass	Pass	Fail	ND
215*	Pass	Pass	ND	Pass	Pass
216	Fail	Fail	Fail	Pass	ND
217	Fail	Fail	Fail	Pass	ND
218	Pass	Fail	Pass	Pass	ND
219	Pass	Fail	ND	Pass	Fail
220	Pass	Fail	ND	Pass	Pass
221	Pass	Fail	Pass	Pass	Pass
222	Pass	Fail	Fail	Pass	ND
223	Pass	Fail	ND	Pass	ND
224	Pass	Fail	ND	Pass	Pass
225	Pass	Fail	ND	Pass	Pass
226	Pass	Fail	ND	Pass	Pass

*Substrate must be heated to at least 100°F prior to application.

Note: ND = No data

application of the foam. Such a procedure would obviously be impractical in most mines. Isocyanurate would have been a potential candidate in all other respects.

Candidates Selected for Testing

Selecting the best 30 foams for testing from the 36 candidates in Table 4 proved to be difficult. The data of Table A-2 were evaluated in cooperation with the TPO, and subsequent discussions held with suppliers, resulting in the elimination of several: The nitrile/vinyl candidate (Item 105) comes in sheets and must be glued in place; a urea/formaldehyde (Item 111) was dropped because of a decision by Ciba-Geigy to discontinue its sale in the U.S. because of the formaldehyde vapor con troversy. Since this was likely to be a pattern and the second urea/formaldehyde candidate (Item 112) was also very low density (0.7 pcf),it was also dropped. The two high-density silicone candidates (Items 108 and 109) were dropped in favor of the two lower density foams. Their evaluation properties, in other respects, were similar.

A list of 31 foams remained for laboratory testing. When samples of these foam systems were ordered, however, some had been discontinued. Others had either been assigned new stock numbers or replaced with a similar formulation: Two isocyanurates (Items 101 and 104) and two urethanes (Items 112 and 113) had been discontinued. Item 103 was now called Texthane 301-20; Item 121 was replaced by Coro-Foam C444, and Item 135 was replaced by SS-0768.

Another urethane, Olin's Autofroth 741E-02 (Item 126), was available but could only be obtained by purchasing large quantities of the foam and the mixing equipment at a high cost. The supplier claimed that it was essentially the same material as their Polysystem 7622-02 (Item 127) except for the method of application (froth vs spray). Item 126, therefore, was also rejected.

Later, Foam Systems Company informed us that their FS 55 was an excellent isocyanurate foam that had been used successfully in a number of high temperature applications. Since only two other isocyanurate foams were on the list, FS 55 was also added.

The final list of 27 foam candidates for testing is shown in Table 7. The item number for the candidates shown in the table will be used throughout the remainder of this report for identification, and is cross-referenced to Table 4 by the number in parenthesis and Product Identity.

CANDIDATE SAMPLE PREPARATION

Twenty-four foam formulations were obtained from the manufacturers or their distributors. A Binks Variable-C pumping unit, coupled to a Binks 18FM gun, was used to prepare 22 foam samples for testing. One of the remaining, the Dow-Corning silicone foam (Item 3, Table 7), was

TABLE 7

Identification of foams selected for testing

Item no	Foam sample 1676-	Generic* type	Product identity	Supplier of foam system
1 (102)	48-2	ICU	ICU Kit	Insta-Foam Products
2 (103)	48-13	ICU	Texthane 301-20	Texas Urethanes
3 (107)	50-1	Silicone	3-6548 RTV	Dow-Corning
4 (115)	48-11	RUF	RIGIMIX E/F	Callery Chemical/Mine Safety Appl.
5 (116)	48-12	RUF	X-156	Callery Chemical/Mine Safety Appl.
6 (117)	46-4	RUF	CSI 8420	Chemetics Systems
7 (118)	46-3	RUF	CSI 9120	Chemetics Systems
8 (119)	46-1	RUF	CSI 9152	Chemetics Systems
9 (120)	48-9	RUF	Coro-Foam G325	Cook Paint & Varnish
10 (121)	48-10	RUF	Coro-Foam C444	Cook Paint & Varnish
11 (122)	46-10	RUF	FS 24	Foam Systems Co.
12 (123)	46-11	RUF	FS 25	Foam Systems Co.
13 (124)	46-12	RUF	FS 234	Foam Systems Co.
14 (125)	48-7	RUF	Chempol 30-2038/30-2124	Freeman Chemical
15 (127)	48-6	RUF	Polysystem 7622	Olin Corporation
16 (128)	46-6	RUF	FMS 20	Polymir
17 (129)	48-1	RUF	Texthane 220-20	Texas Urethanes
18 (130)	48-8	RUF	UFS 250	United Foam
19 (131)	46-5	RUF	Isonate CPR 468	Upjohn Company
20 (132)	46-9	RUF	USC 230	Urethane Systems Corp.
21 (133)	46-13	RUF	FMS 20	Utah Foam Products
22 (134)	46-8	RUF	SS-0640	Witco Chemical
23 (135)	46-7	RUF	SS-0768	Witco Chemical
24 (110)	50-2**	Silicone	RTV-850	General Electric
25 (136)	50-3**	FUF	Hypol RHP 2000 HD	W. R. Grace
26 (106)	50-5**	Phenolic	1B-322/1D-644	Reichhold Chemical, Ltd.
27 (-)	50-4	ICU	FS 55	Foam Systems Company

Note: *ICU = Isocyanurate Foam
RUF = Rigid Urethane Foam
FUF = Filled Urethane Foam

**Foam samples prepared by supplier

(xxx) Corresponding Item No. on Table 3

hand mixed and poured, because of its very high viscosity. The other, Insta-Foam ICU Kit (Item 1, Table 7), came complete with its own mixing nozzles, and was used as received. All foam samples were prepared at the recommended ratios.

The three remaining foams of the 27 selected was prepared by the manufacturer. The General Electric Silicone (Item 24, Table 7) was prepared at a General Electric plant using an experimental pumping unit and a static mixer. The foam was poured rather than sprayed because of its high viscosity. General Electric claimed, however, that this formulation has been sprayed using a Binks C pumping unit and a Binks 18 FM gun with no problems.

W.R. Grace's Hypol-based foam (Item 25, Table 7) was prepared at their Research Center using prototype spray equipment. Although the materials were readily sprayed, the slow reactivity of the system made it difficult to prepare foam on a vertical surface.

The phenolic foam (Item 26, Table 7) was supplied as board stock by Reichhold Chemicals, Ltd. It was prepared, not in our presence, using commercial type equipment. Although this foam was designed for pouring on a production line, Reichhold claimed that it could be modified for spraying with conventional urethane spray equipment.

The fact that both the silicone and phenolic foams had to be poured rather than sprayed made them somewhat unsuitable for underground use. Nevertheless, these foams were evaluated because of their unique composition and reputed high resistance to fire.

No difficulties were encountered in preparing the foam samples. Four of the foam systems (Items 6, 8, 16 and 19, Table 7) were slower in reacting than desirable, but this could result from either the design of the formulation or from a short shelf life.

FOAM TESTING

Flame Spread Evaluation

The ability to seal both the face and perimeter of a stopping is an important characteristic of a rigid foam for this proposed use. Equally important, however, is the property to resist flame propagation. The flame spread index (I_s) of a foam, as determined by the ASTM E162 test, is an accepted measure of this property.

The candidate foams were subjected to two laboratory-scale flame spread tests: the ASTM E162 test; and a Callery Chemical Company's modification of E162 (designated E162-CCC-2). The results of these tests were used to select 16 of the most promising for further testing.

ASTM E162 Tests - All 27 candidate foam samples were subjected to the ASTM E162 Radiant Panel Test. In the test, one inch thick 6 in. x 18 in. samples of the foam are clamped into the sample holder (Figures 2 and 3) and exposed to a gas-fired radiant panel of a specific heat flux. A pilot flame ignites the upper edge and the flame front progress down the sample is monitored as a function of time. The total test time is 4 minutes.

The sample off-gas captured in the exhaust stack is also monitored for temperature and smoke content (by light obscuration). The peak temperature is compared to a baseline temperature to obtain a temperature rise (ΔT) for the sample, and is combined with the burning rate data to calculate the flame spread index (I_s). Both a peak and an integrated (total) smoke content are recorded for comparison.

The flame spread index (I_s) is the product of the heat evolution factor (Q) and the flame spread factor (F).

$$I_s = FQ$$

The heat evolution (Q) is the increase in stack temperature multiplied by 0.1 and divided by a constant β, which is the thermocouple response to a known but varied range of heat inputs in btu's. Hence,

$$Q = \frac{0.1 \Delta T}{\beta}$$

The flame spread (F) is a function of the speed with which the flame front advances between three-inch-spaced bench marks. Mathematically, the flame spread factor may be expressed as:

$$F = 1 + \frac{1}{t_6 - t_3} + \frac{1}{t_9 - t_6} + \frac{1}{t_{12} - t_9} + \frac{1}{t_{15} - t_{12}}$$

where t.....equals the time in minutes that the flame reaches the 3, 6, 9, 12 and 15 inch marks.

The percent obscuration caused by generated smoke was measured by a photoelectric device as it passed through the vent stack of the hood. The peak recorded smoke datum was 3 times the percent obscuration. The smoke area datum was the area under the smoke curve (3 x percent obscuration x minutes).

Most of the rigid foam samples for testing were prepared by spraying the materials on large cardboard sheets and sawing to size. The flexible or semi-rigid foams (Items 3, 24 and 25, Table 7) were prepared on cement asbestos board so that they would not fall out of the holders during the radiant panel tests. Four samples of each foam were tested except for Reichhold Chemicals phenolic foam (Item 26). Only two samples of this foam were used due to a short supply.

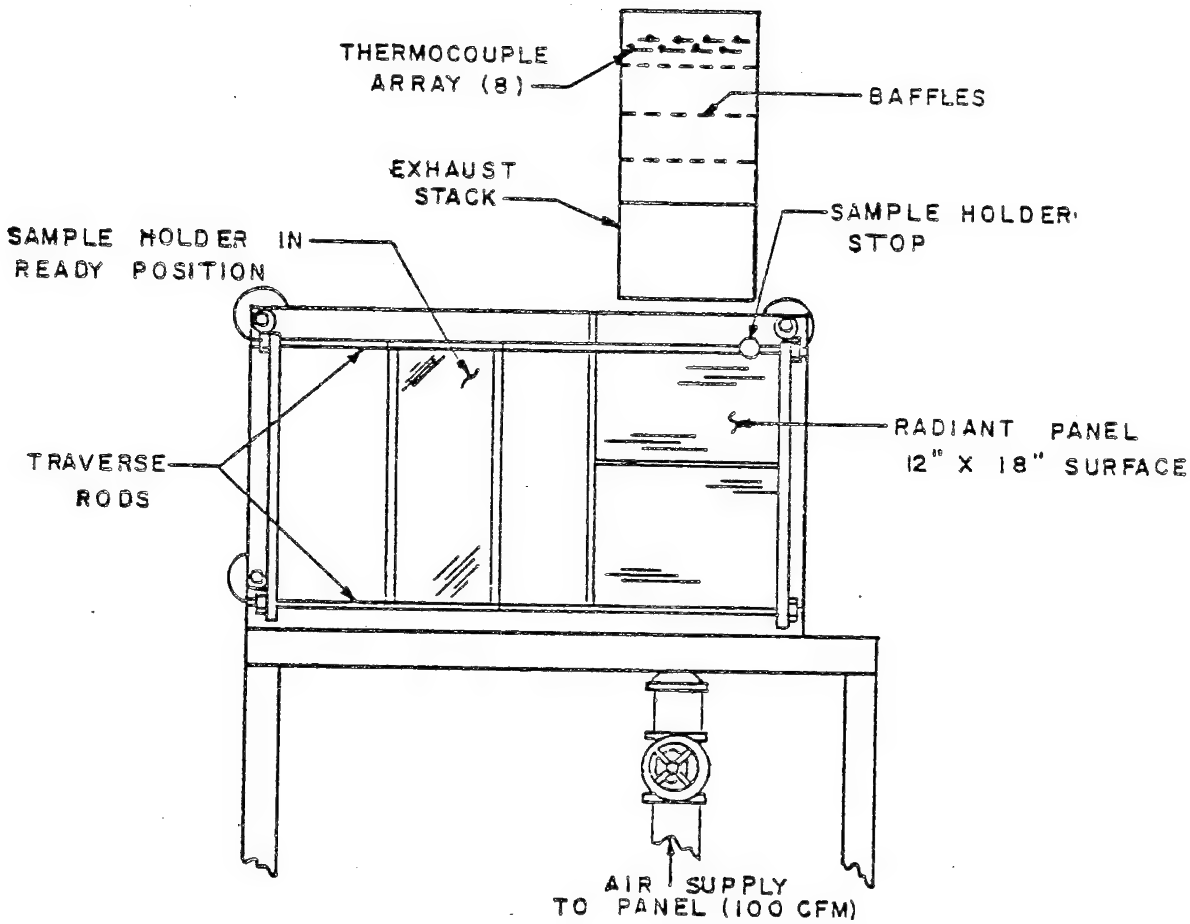


FIGURE 2 - E162 Radiant panel test facility (front view)

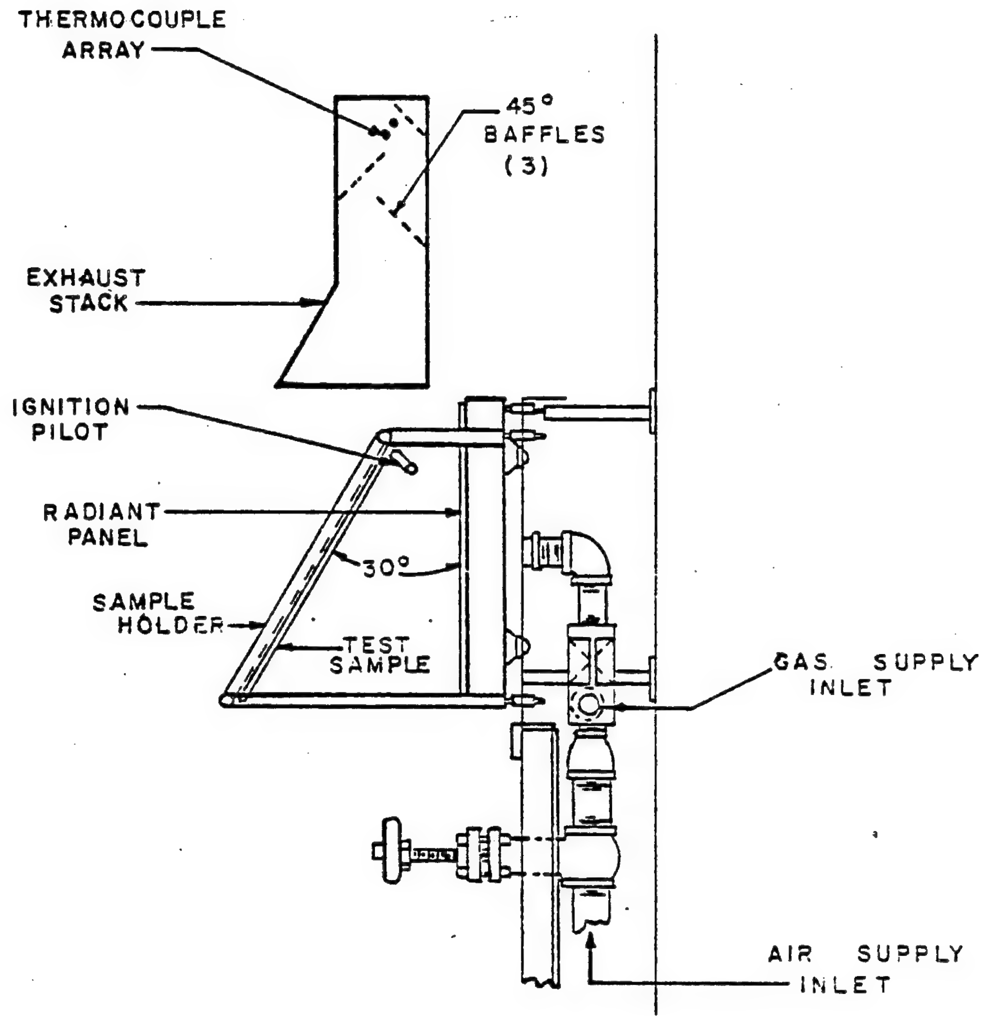


FIGURE 3 - E162 Radiant panel test facility (side view)

The data obtained in the E162 tests are shown in Table 8 along with the averge and standard deviation.

E162-CCC-2 Tests - The E162-CCC-2 test is a more severe variation of the ASTM E162 test. The changes, and comparison with the conventional test facility, are illustrated in Figures 2, 3 and 4.

The front view (Figure 2) of both the ASTM E162 and E162-CCC-2 test facility is identical. Figure 3 shows a side view of the standard E162 test facility, while Figure 4 is a similar view of the modified version. The basic changes made were:

1. The angle of the test sample in relation to the radiant panel was reversed, with the bottom of the test sample placed at the same distance from the radiant panel as the top was in the ASTM E162. The angle at the bottom of the sample away from the panel is set at 25°.

2. The ignition pilot was moved from the top to the bottom of the sample.

3. The exhaust stack was moved back from the panel and essentially centered over the sample to collect the heat and smoke.

The data collected and calculations are the same as in the ASTM E162 test.

Four samples of each of the 27 foams were subjected to the E162-CCC-2 modified radiant panel test (only two samples of Item 26 (1676-50-5) were used due to a limited supply of the foam). The data are shown in Table 9 along with the averages and standard deviation.

Flame Spread Index (I_S) - The flame spread index is a function of the rate and distance of flame propagation and heat of reaction. The data for both radiant panel tests are summarized in Table 10. These data may be conveniently grouped into five ranges. These groups and ranges are shown in Table 11, with Group A being best and Group E the poorest. Items 4, 5, 9, 11, 14, 15, 17, 22, 23, 24, 25, 26 and 27 appear in Groups A, B and C by both tests. Items 2, 3, 7, 13, 18, 19 and 21 fit into these three groups by one of the test methods. Those foams falling into Groups D and E by both tests include Items 1, 6, 8, 10, 12, 16 and 20.

The silicone and Hypol-based foams (Items 3, 24 and 25) deserve special comment. All three of these foams are properly classed as "flexible" or "semi-rigid" rather than rigid foams. When flexible or semi-rigid foams are exposed to the heat of the radiant panel test, they tend to distort and in so doing move closer to the heat source and increase the radiant heat to which they are subjected. Wire mesh is often used to prevent this distortion, but that effectively alters the foam exposure and introduces unknown errors. This happened with Item 3.

TABLE 8

ASTM E162 Radiant panel data on virgin foams

Sample 1676-	Q	F	Is	In burned	Smoke* Peak	Smoke* Area	Sample 1676-	Q	F	Is	In burned	Smoke Peak	Smoke Area
46-1	13.0	64.3	834	17	58.5	6765	46-6	17.5	23.3	407	15	41.5	8380
Item 8	12.5	58.3	727	17	46.5	6356	Item 16	13.0	31.9	413	17	49.0	6950
	8.1	64.7	522	17	39.5	4440		13.8	20.5	282	13	49.5	7210
	8.9	58.7	523	17	42.0	8860+		11.0	18.7	206	13	36.5	ND
Avg	10.6	61.5	651	17	46.6	6605	Avg	13.8	23.6	327	14.5	44.1	7513
Std dev	2.5	3.5	155	0	8.4	1813	Std dev	2.7	5.9	101	1.9	6.3	762
46-3	8.4	(106)	(889)	9	25.0	3040	46-7	4.5	2.9	13	3	9.5	1232
Item 7	7.7	31.3	241	9	25.5	3200	Item 23	4.6	3.0	14	3	12.5	1570
	8.6	21.6	185	9	21.5	2660		4.3	2.4	10	3	12.5	1440
	7.5	6.3	47	6	22.5	2640		6.2	2.5	16	3	13.5	1890
Avg	8.0	19.7	158	8.3	23.6	2885	Avg	4.9	2.7	13	3	12.0	1533
Std dev	0.6	12.6	100	1.5	1.9	279	Std dev	0.9	0.3	2	0	1.7	276
46-4	5.8	95.7	550	18	28.5	3080	46-8	4.7	34.1	161	10	24.5	1950
Item 6	6.2	119	734	18	29.0	2310	Item 22	4.3	37.0	159	9	26.0	2210
	4.9	94.9	469	17	ND	ND		5.8	35.5	207	11	27.0	2500
	4.6	80.9	374	18	20.0	2940		7.9	(115)	(905)	10	31.5	2210
Avg	5.4	97.5	532	17.8	25.8	2777	Avg	5.7	35.5	176	10.0	27.3	2218
Std dev	0.7	15.6	153	0.5	5.1	410	Std dev	1.6	1.5	27	0.8	3.0	225
46-5	5.4	6.1	33	3	13.0	2040	46-9	5.7	141	801	18	41.5	4880
Item 19	5.6	10.5	59	3	15.0	1580	Item 20	5.8	156	897	18	55.0	6560
	5.4	8.0	43	3	14.5	1660		5.9	114	673	18	44.0	3850
	5.9	4.9	29	3	13.0	1985		6.9	109	755	18	63.5	4740
Avg	5.6	7.4	41	3	13.9	1816	Avg	6.1	130	782	18	51.0	5008
Std dev	0.2	2.5	13	0	1.0	230	Std dev	0.6	22	94	0	10.2	1131

TABLE 8 (cont)

ASTM E162 Radiant panel data on virgin foams

Sample 1676-	Q	F	Is	In burned	Smoke Peak	Smoke Area	Sample 1676-	Q	F	Is	In burned	Smoke Peak	Smoke Area
46-10	4.1	15.0	62	6	16.5	2110	48-1	4.7	13.0	61	3	15.0	1890
Item 11	3.6	17.4	63	6	19.0	2385	Item 17	5.8	13.9	81	3	14.5	1510
	2.8	22.0	60	6	21.5	2660		5.1	10.2	52	4	11.5	1910
	3.4	25.0	85	8	18.0	2160		4.9	(103)	(507)	6	11.0	(1050+)
Avg	3.5	19.8	68	6.5	18.8	2329	Avg	5.1	12.4	65	4.0	13.0	1770
Std dev	0.6	4.5	12	1.0	2.1	251	Std dev	0.5	1.9	15	1.4	2.0	225
46-11	7.7	14.9	114	8	11.5	1930	48-2	6.8	57.5	393	15	62.5	4420
Item 12	6.3	136	862	16	25.5	2250	Item 1	6.2	56.0	349	14	58.0	3565
	5.3	134	707	16	25.0	2910		4.5	61.1	278	14	57.5	3770
	3.8	122	469	9.5	26.5	3030		5.3	64.8	343	17	58.5	4130
Avg	5.8	102	538	12.0	22.1	2530	Avg	5.7	59.9	341	15.0	59.1	3971
Std dev	1.6	58	326	4.0	7.1	527	Std dev	1.0	3.9	47	1.4	2.3	380
46-12	3.7	113	423	17	34.0	3050	48-6	5.4	2.3	12	3	15.5	(1100+)
Item 13	4.1	56.5	229	17	56.5	2910	Item 15	5.8	2.1	12	3	18.0	1725
	4.4	77.4	338	15.5	37.0	3140		5.8	2.2	12	3	16.5	1870
	4.9	76.8	373	9	36.5	2170		5.8	2.2	13	3	14.5	1190
Avg	4.3	80.9	341	14.6	41.0	2818	Avg	5.7	2.2	12	3	16.1	1595
Std dev	0.5	23.5	82	3.8	10.4	442	Std dev	0.2	0.1	0	0	1.5	358
46-13	6.3	10.8	68	5	14.0	1920	48-7	4.6	2.6	12	4	12.5	1515
Item 21	4.8	16.4	78	5	14.0	1840	Item 14	3.5	2.5	9	4	10.5	1502
	5.4	14.1	76	5	12.0	1750		4.2	2.1	9	3	11.5	1330
	5.5	20.1	111	7	12.5	1930		4.5	2.6	12	3	ND	ND
Avg	5.5	15.4	83	5.5	13.1	1860	Avg	4.2	2.5	10	3.5	11.5	1449
Std dev	0.6	3.9	19	1.0	1.0	84	Std dev	0.5	0.2	2	0.6	1.0	103

TABLE 8 (cont)

ASTM E162 Radiant panel data on virgin forma

Sample 1676-	Q	F	Is	In burned	Smoke Peak	Smoke Area
48-8	6.2	8.1	50	4	11.5	2067
Item 18	7.2	7.3	53	4	10.5	ND
	8.1	(113)	(912)	5	10.5	1750
	7.5	12.7	95	5	13.5	1920
Avg	7.3	9.4	66	4.5	11.5	1912
Std dev	0.8	2.9	25	0.6	1.4	159
48-9	1.8	51.0	91	9	21.0	1330
Item 9	2.9	57.9	169	10	22.0	1930
	1.5	54.5	80	9	23.5	1570
	1.5	75.5	110	17	22.0	2395
Avg	1.9	59.7	112	11.3	22.1	1806
Std dev	0.7	10.9	40	3.9	1.0	464
48-10	14.1	47.7	673	18	53.0	7840
Item 10	12.6	47.0	594	18	55.0	8070
	10.2	39.3	401	18	63.0	7900
	13.0	38.7	502	18	51.0	ND
Avg	12.5	43.2	543	18	55.5	7937
Std dev	1.6	4.9	118	0	5.3	119
48-11	5.2	33.8	175	11.0	21.0	2510
Item 4	5.4	27.5	149	11.5	27.5	3210
	3.9	34.1	134	12.0	24.0	2795
	4.6	25.9	118	11.0	26.0	2741
Avg	4.8	30.3	144	11.4	24.6	2814
Std dev	0.7	4.2	24	0.5	2.8	292

Sample 1676-	Q	F	Is	In burned	Smoke Peak	Smoke Area
48-12	1.4	1.0	1	1	10.5	1100
Item 5	1.9	1.0	2	1	12.0	1060
	2.8	1.0	3	1	10.0	1390
	2.0	1.0	2	1	11.5	850
Avg	2.4	1.0	2	1	11.0	1100
Std dev	0.9	0	1	0	0.9	222
48-13	7.3	102	747	7.5	27.5	2760
Item 2	6.3	103	648	6	19.5	2100
	5.0	6.1	31	6	16.5	1660
	6.3	18.7	118	9	20.5	2200
Avg	6.2	57.4	386	7.1	21.0	2180
Std dev	0.9	52.4	364	1.4	4.7	452
50-1	34.3	9.6	329	14	23.5	12140
Item 3	55.1	10.2	559	14	35.5	15500
	28.7	10.6	305	14	13.0	12680
	30.0	10.4	311	15	12.5	10510
Avg	37.0	10.2	376	14.3	21.1	12708
Std dev	12.3	0.5	122	0.5	10.8	2078
50-2**	8.9	9.1	81	14	9	ND
Item 24	8.4	8.1	68	14	7	8670
	8.6	9.2	79	14	5	5290
	7.8	9.0	70	14	8	8320
Avg	8.4	8.9	75	14	7.3	7427
Std dev	0.5	0.5	6	0	1.7	1859

TABLE 8 (cont)

ASTM E162 Radiant panel data on virgin foams

Sample 1676-	Q	F	Is	In burned	Smoke Peak	Smoke Area
50 - 3**	5.7	2.7	15	3	5	2550
Item 25	5.8	2.4	14	3	4	2650
	4.9	2.4	12	3	1	3300
	10.2	2.3	23	3	2	4050
Avg	6.6	2.4	16	3	3.0	3138
Std dev	2.4	0.2	5	0	1.8	693
50 - 4	6.0	13.6	82	9	24.0	3000
Item 27	7.3	15.9	116	9	34.0	3260
	7.3	14.4	105	9	40.0	ND
	7.0	12.3	86	10	30.0	4420
Avg	6.9	14.0	97	9.3	32.0	3560
Std dev	0.6	1.5	16	0.5	6.7	756
50 - 5	3.2	1	3	<3	0	0
Item 26	1.6	1	2	<3	0	0
Avg	2.4	1	3	<3	0	0
Std dev	0.9	0	1	0	0	0

Notes: *Peak smoke = 3 x % Obscuration

*Smoke area = Area under smoke curve (3 x % Obscuration x Minutes)

**Prepared on cement asbestos board

(-) These numbers were not used in the calculations. They seemed to be incomplete or spurious.

ND = No data

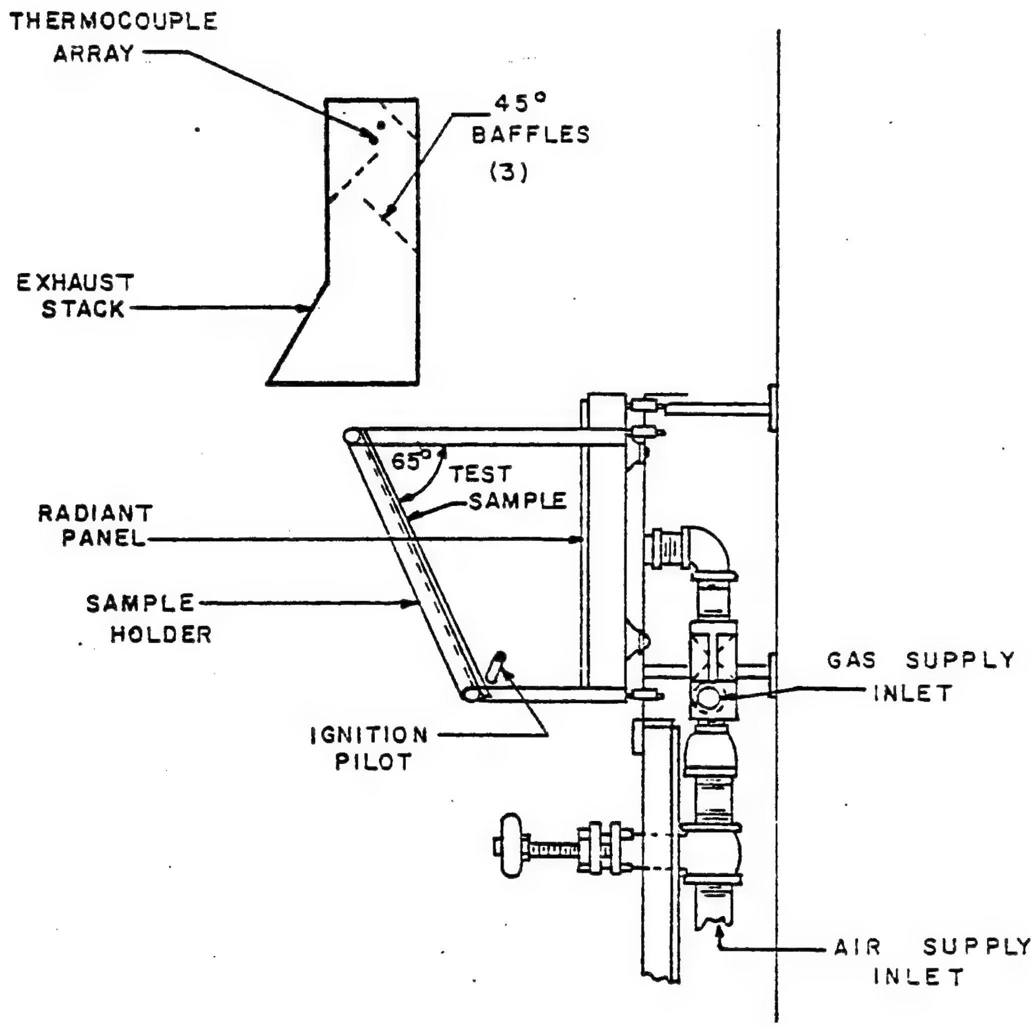


FIGURE 4 - E162-CCC-2 Modified radiant panel test facility (side view)

TABLE 9

E162-CCC-2 Modified radiant panel data on virgin foams

Sample 1676-	Q	F	Is	In burned	Smoke Peak	Smoke Area	Sample 1676-	Q	F	Is	In burned	Smoke Peak	Smoke Area
46-1	20.7	251	5196	18	89	6300	46-6	21.5	134	2882	18	94	10900
Item 8	27.4	251	6877	18	90	(13110)	Item 16	30.5	134	4097	18	100+	9560+
	15.3	251	3840	18	94	7600		24.5	134	3294	18	100+	1080+
	14.9	251	3740	18	93	6660		27.3	134	3666	18	75	9350
Avg	19.6	251	4913	18	91.5	6853	Avg	26.0	134	3485	18	92+	10223+
Std dev	5.8	0	1468	0	2.4	671	Std dev	3.8	0	519	0	12+	893+
46-3	10.2	284	2905	18	75	7130	46-7	6.0	351	2102	18	46.5	3290
Item 7	7.5	284	2118	18	76	7740	Item 23	5.8	351	2050	18	44	3260
	10.2	284	2905	18	67	ND		5.6	251	1393	18	39	3230
	6.4	284	1825	18	73	8150		5.8	251	1448	18	45.5	3230
Avg	8.6	284	2438	18	72.8	7673	Avg	5.8	301	1748	18	43.8	3253
Std dev	1.9	0	552	0	4.0	513	Std dev	0.2	58	380	0	3.3	29
46-4	13.4	251	3371	18	29.5	2690	46-8	9.5	103	975	18	78	5990
Item 6	13.9	251	3481	18	25	4000	Item 22	8.8	109	951	18	68	5390
	14.2	209	2964	18	26.5	4510		10.5	94	983	18	77.5	5600
	9.9	209	2076	18	34.5	4400		10.2	99	1013	18	79	5420
Avg	12.9	230	2973	18	28.9	3900	Avg	9.7	101	981	18	75.6	5600
Std dev	2.0	24	638	0	4.2	836	Std dev	0.8	6	26	0	5.1	276
46-5	10.1	351	3545	18	54	4340							
Item 19	9.2	351	3229	18	54	4620							
	9.1	351	3159	18	53	3740							
	8.0	351	2808	18	54	ND							
Avg	9.1	351	3185	18	53.8	4233							
Std dev	0.9	0	302	0	0.5	450							

TABLE 9 (cont)

E162-CCC-2 Modified radiant panel data on virgin foams

Sample 1676-	Q	F	Is	In burned	Smoke Peak	Smoke Area
46-9	13.4	351	4703	18	94	ND
Item 20	13.0	351	4563	18	90	7700
	11.7	351	4107	18	92	8280
	11.7	351	4100	18	91	8690
Avg	12.5	351	4368	18	91.8	8223
Std dev	0.9	0	311	0	1.7	497
46-10	4.4	148	647	18	50.5	3630
Item 11	4.7	234	1094	18	56.5	4200
	5.0	130	646	18	56.5	7160
	4.4	168	735	18	49.5	3335
Avg	4.6	170	781	18	53.5	4581
Std dev	0.3	45	213	0	3.8	1756
46-11	9.5	268	2540	18	58	3580
Item 12	9.5	268	2540	18	60.5	3760
	8.3	268	2227	18	63	3950
	9.8	268	2618	18	60.5	3640
Avg	9.3	268	2481	18	60.5	3733
Std dev	0.6	0	173	0	2.0	163
46-12	4.2	309	1287	18	60	4330
Item 13	4.7	309	1445	18	61	2890
	4.1	309	1265	18	58	2825
	4.1	276	1129	18	53	3160
Avg	4.3	301	1282	18	58.0	3301
Std dev	0.2	17	129	0	3.6	701

Sample 1676-	Q	F	Is	In burned	Smoke Peak	Smoke Area
46-13	6.6	351	2331	18	58	3540
Item 21	5.6	351	1948	18	52	3020
	6.4	351	2253	18	61	3230
	6.1	351	2127	18	55	3550
Avg	6.2	351	2165	18	56.5	3335
Std dev	0.5	0	167	0	3.9	257
48-1	8.5	201	1702	18	58	5320
Item 17	8.5	201	1702	18	66.5	ND
	8.0	184	1480	18	60	5180
	7.2	184	1318	18	59	5340
Avg	8.0	193	1551	18	60.9	5280
Std dev	0.6	10	187	0	3.8	87
48-2	12.9	168	2155	18	90	4920
Item 1	11.4	168	1910	18	85	4730
	12.0	168	2007	18	98	5250
	15.2	168	2546	18	85.5	4550
Avg	12.9	168	2155	18	89.6	4863
Std dev	1.7	0	280	0	6.0	299

TABLE 9 (cont)

E162-CCC-2 Modified radiant panel data on virgin foams

Sample 1676-	Q	F	Is	Inches burned	Smoke Peak	Smoke Area	Sample 1676-	Q	F	Is	Inches burned	Smoke Peak	Smoke Area
48-6	6.1	218	1326	18	36.5	3715	48-10	20.9	168	3502	18	68	6540
Item 15	5.6	218	1208	18	39	3700	Item 10	18.3	301	5493	18	74.5	6130
	5.7	218	1239	18	40	3855		20.2	151	3043	18	70	ND
	5.6	218	1208	18	36	3680		14.6	151	2205	18	86.5	5920
Avg	5.7	218	1245	18	37.9	3738	Avg	18.5	193	3561	18	74.8	6197
Std dev	0.3	0	56	0	1.9	80	Std dev	2.8	73	1396	0	8.3	315
48-7	4.3	143	608	18	42.5	2860	48-11	9.1	171	1547	18	72	6440
Item 14	4.1	143	584	18	41	ND	Item 4	7.6	171	1298	18	62	6370
	4.4	168	745	18	44.5	3480		7.3	171	1248	18	61	5560
	5.0	168	842	18	44.5	3290		8.0	171	1373	18	78.5	6830
Avg	4.5	156	696	18	43.1	3210	Avg	8.0	171	1367	18	68.4	6300
Std dev	0.4	14	122	0	1.7	318	Std dev	0.8	0	131	0	8.4	533
48-8	9.1	301	2724	18	71	4340	48-12	0.5	101	52	3	30	2420
Item 18	9.5	301	2856	18	71	4460	Item 5	0.2	101	15	3	34	2500
	9.5	301	2856	18	69	ND		0.4	101	44	3	32	2620
	9.8	301	2944	18	59	4960		0.4	101	44	3	32.5	2330
Avg	9.5	301	2845	18	67.5	4587	Avg	0.4	101	39	3	32.1	2468
Std dev	0.3	0	91	0	5.7	329	Std dev	0.1	0	16	0	1.7	123
48-9	2.5	171	424	18	32.5	2920							
Item 9	5.2	171	886	18	35.5	3020							
	4.1	143	585	18	35.5	3630							
	4.1	168	686	18	35.5	2900							
Avg	4.0	163	645	18	34.8	3118							
Std dev	1.1	14	193	0	1.5	346							

TABLE 9 (cont)

E162-CCC-2 Modified radiant panel data on virgin foams

Sample 1676-	Q	F	Is	In burned	Smoke Peak	Smoke Area
48-13	5.5	163	890	18	52	3630
Item 2	(12.0)	159	(1907)	18	(82)	(6250)
	5.1	146	746	18	55	4210
	5.8	133	766	18	51	4630
Avg	5.5	150	801	18	52.7	4157
Std dev	0.3	14	78	0	2.1	502
50-1	(71.8)	(18.3)	(1314)	(18)	(24)	(17620)
Item 3	11.0	11.8	129	15	7	9490
	11.0	11.5	126	15	4.5	4740
	9.5	11.8	112	15	6.5	4230
Avg	10.5	11.7	122	15	6.0	6153
Std dev	0.9	0.2	9	0	1.3	2901
50-2*	43.2	12.6	542	12	7.0	5860
Item 24	30.1	11.7	351	12	6.5	7590
	41.8	12.7	529	12	5.0	7380
	45.9	15.1	692	12	8.0	11270
Avg	40.2	13.0	529	12	6.6	8025
Std dev	6.9	1.5	140	0	1.3	2297
50-3*	-2.7	1	-3	1	4	(4010+)
Item 25	-1.4	1	-1	1	7	8260
	-1.4	1	-1	1	0	9110
	8.2	1	8	1	0	7830
Avg	0.7	1	1	1	5.5	8400
Std dev	5.1	0	5	0	1.5	651

Sample 1676-	Q	F	Is	In burned	Smoke Peak	Smoke Area
50-4	11.7	152	1772	15	75	5370
Item 27	11.8	113	1333	15	69	5190
	8.0	113	905	15	71	5180
	8.5	102	865	15	72	5230
Avg	10.0	120	1219	15	71.8	5243
Std dev	2.0	22	425	0	2.5	88
50-5	2.5	1	3	<3	2	(5380)
Item 26	3.0	1	3	<3	2	4570
Avg	2.8	1	3	<3	2	4970+
Std dev	0.4	0	0	0	0	NM

Note: (-) These numbers were not used in the calculations. They seemed to be incomplete or spurious.

ND = No data

NM = Not meaningful

*Prepared on cement asbestos board.

TABLE 10

Summary of radiant panel data on virgin foams

Standard ASTM E162 & modified E162-CCC-2

Item no	Foam sample 1676-	Q		F		Is		In burned		Smoke Peak		Smoke Area	
		Std	Mod	Std	Mod	Std	Mod	Std	Mod	Std	Mod	Std	Mod
1	48-2	5.7	12.9	59.9	168	341	2155	15.0	18	59.1	89.6	3971	4863
2	48-13	6.2	5.5	57.4	150	386	801	7.1	18	21.0	52.7	2180	4157
3	50-1	37.0	10.5	10.2	11.7	376	122	14.3	15	21.1	6.0	12708	6153
4	48-11	4.8	8.0	30.3	171	144	1367	11.4	18	24.6	68.4	2814	6300
5	48-12	2.4	0.4	1	101	2	39	1	3	11.0	32.1	1100	2468
6	46-4	5.4	12.9	97.5	230	532	2973	17.8	18	25.8	28.9	2777	3900
7	46-3	8.0	8.6	19.7	284	158	2438	8.3	18	23.6	72.8	2885	7673
8	46-1	10.6	19.6	61.5	251	651	4913	17	18	46.6	91.5	6605	6853
9	48-9	1.9	4.0	59.7	163	112	645	11.3	18	22.1	34.8	1806	3118
10	48-10	12.5	18.5	43.2	193	543	3561	18	18	55.5	74.8	7937	6197
11	46-10	3.5	4.6	19.8	170	68	781	6.5	18	18.8	53.5	2329	4581
12	46-11	5.8	9.3	102	268	538	2481	12.0	18	22.1	60.5	2530	3733
13	46-12	4.3	4.3	80.9	301	341	1282	14.6	18	41.0	58.0	2818	3301
14	48-7	4.2	4.5	2.5	156	10	696	3.5	18	11.5	43.1	1449	3210
15	48-6	5.7	5.7	2.2	218	12	1245	3	18	16.1	37.9	1595	3738
16	46-6	13.8	26.0	23.6	134	327	3485	14.5	18	44.1	92+	7513	10223+
17	48-1	5.1	8.0	12.4	193	65	1551	4.0	18	13.0	60.9	1770	5280
18	48-8	7.3	9.5	9.4	301	66	2845	4.5	18	11.5	67.5	1912	4587
19	46-5	5.6	9.1	7.4	351	41	3185	3	18	13.9	53.8	1816	4233
20	46-9	6.1	12.5	130	351	782	4368	18	18	51.0	91.8	5008	8223
21	46-13	5.5	6.2	15.4	351	83	2165	5.5	18	13.1	56.5	1860	3335
22	46-8	5.7	9.7	35.5	101	176	981	10.0	18	27.3	75.6	2218	5600
23	46-7	4.9	5.8	2.7	301	13	1748	3	18	12.0	43.8	1533	3253
24	50-2	8.4	40.2	8.9	13.0	75	529	14	12	7.3	6.6	7427	8025
25	50-3	6.6	0.7	2.4	1	16	1	3	1	3.0	5.5	3138	8400
26	50-5	2.4	2.8	1	1	3	3	<3	<3	0	2	0	4970+
27	50-4	6.9	10.0	14.0	120	97	1219	9.3	15	32.0	71.8	3560	5243
	Avg	7.3	10.2	34.9	192	229	1821	9.5	14.9	24.6	55.4	3464	5060
	Std dev	6.9	8.5	38.9	104	249	1394	5.7	6.0	16.2	25.5	2807	1999

TABLE 11

Flame spread index (I_s) ranges

	ASTM E162			E162-CCC-2		
Group	Range	No	Item nos	Range	No	Item nos
A	2-16	6	5, 14, 15, 23, 25 & 26	1-122	4	3, 5, 25 & 26
B	41-112	8	9, 11, 17, 18, 19, 21, 24 & 27	529-981	6	2, 9, 11, 14, 22 & 24
C	144-176	3	4, 7 & 22	1219-1748	6	4, 13, 15, 17, 23 & 27
D	327-386	5	1, 2, 3, 13 & 16	2155-2481	4	1, 7, 12 & 21
E	532-782	5	6, 8, 10, 12 & 20	2845-4913	7	6, 8, 10, 16, 18, 19 & 20

To prevent this from happening to Items 24 and 25, the samples were prepared directly on a section of cement asbestos board. This arrangement more nearly represents a real life situation in which the foam will be attached to its substrate. The strategy seemed to work quite satisfactorily.

In general, comparisons of the data obtained from tests ASTM E162 and E162-CCC-2 produced similar groupings of the candidate materials. Forty-four percent were in the same group in Table 11 and 74% were no more than one group apart. Only three foams (11%) were three or more groups apart. The more severe E162-CCC-2 increased the I_s values by a little less than an order of magnitude. In our opinion, this method is a useful tool for separating foams having lower flame spread values by ASTM E162 test.

Distances Burned - The flame spread index (I_s) is a function of the distance burned and the rate at which it burns. It seems reasonable to expect that the shorter the distance that the flame propagates, the safer the foam. The test data averages for distances burned, shown in Table 10, may be arranged into five groups, with A being the best and E the poorest. These groups and their ranges are shown in Table 12.

TABLE 12

Ranges of flame spread distances

	ASTM E162			E162-CCC-2		
Group	Range(in)	No	Item nos	Range(in)	No	Item nos
A	1-3	6	5, 15, 19, 23, 25 & 26	1-3	3	5, 25 & 26
B	3.5-7.1	6	2, 11, 14, 17, 18 & 21	4-11	0	-
C	8.3-12.0	6	4, 7, 9, 12, 22 & 27	12	1	24
D	14-15	5	1, 3, 13, 16 & 24	15	2	3 & 27
E	17-18	4	6, 8, 10 & 20	18	21	1, 2, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22 & 23

These data show the differences in the distance of flame propagation between the two radiant panel tests. Only six foams failed to burn the entire length of the sample (18 inches) by E162-CCC-2 while six burned three inches or less by ASTM E162.

A correlation of the performances measured for candidate foams by the two test methods was not particularly useful. The increased severity of the E162-CCC-2 test was sufficient to cause most of the foams to burn the entire 18 inches. The 3 foams (Items 5, 25 and 26) in Group A by E162-CCC-2 clearly demonstrated their superior resistance to flame propagation in face of the higher heat flux.

Peak Smoke - The peak smoke values used for comparison were read directly from a chart of percent light obscuration recorded at 30 percent equals full-scale. Absolute values for percent light obscuration, if they are desired, are 30 percent of the recorded number.

The test data average results, shown in Table 10, may be conveniently divided into five groups with A being the best and E the poorest. These groupings are shown in Table 13.

TABLE 13

Ranges of peak smoke values

	ASTM E162			E162-CCC-2		
Group	Range	No	Item nos	Range	No	Item nos
A	0-7.3	3	24, 25 & 26	2-6.6	4	3, 24, 25 & 26
B	11-13.9	7	5, 14, 17, 18, 19, 21 & 23	28.9-37.9	4	5, 6, 9 & 15
C	16.1-32	11	2, 3, 4, 6, 7, 9, 11, 12, 15, 22 & 27	43.1-60.9	9	2, 11, 12, 13, 14, 17, 19, 21 & 23
D	41-46.6	3	8, 13 & 16	67.5-75.6	6	4, 7, 10, 18, 22 & 27
E	51-59.1	3	1, 10 & 20	89.6-92+	4	1, 8, 16 & 20

This general comparison of the data generated by the two test methods shows: 33% are in the same groups by both methods, 92% are no more than one group apart and none are over two groups apart.

Smoke Area - The area under the smoke obscuration curve plotted over time is a measure of the total amount of smoke evolved during the test. Some foams evolve smoke at a low, but fairly continuous level and the result is a large smoke area. Other foams evolve larger amounts of smoke for a very short time (high peak smoke) but return to essentially no smoke, resulting in a small smoke area. The E162-CCC-2 test method gives higher smoke areas due to the increased severity of the test.

The test data average smoke area results, shown in Table 10, can be conveniently arranged into five groups with A being best and E the poorest. These groups are shown in Table 14. A total of 44% falls into

the same group and 92% fall no more than one group apart. No samples were more than two groups apart.

TABLE 14

Ranges of smoke areas

	ASTM E162			E162-CCC-2		
Group	Range	No	Item nos	Range	No	Item nos
A	0	1	26	2468-2497	2	5 & 26
B	1100-1912	9	5, 9, 14, 15, 17, 18, 19, 21, & 23	3118-3900	8	6, 9, 12, 13, 14, 15, 21 & 23
C	2180-3138	9	2, 4, 6, 7, 11, 12, 13, 22 & 25	4157-5600	8	1, 2, 11, 17, 18, 19, 22 & 27
D	3560-3971	2	1 & 27	6153-6853	4	3, 4, 8 & 10
E	5008-12708	6	3, 8, 10, 16, 20 & 24	7673-10223	5	7, 16, 20, 24 25

Selection of Candidates for Further Evaluation - Sixteen (16) of the 27 foams screened by the two radiant panel tests were selected for further evaluation by water immersion. They included the 13 foams found in Groups A, B and C of Table 11 by both tests (Items 4,5,9,11,14,15,17,22, 23,24,25,26 and 27) plus Items 18, 19 and 21 which were in Group B by ASTM E162, although the final three foams were found in Groups D and E by E162-CCC-2, the standard ASTM test value was used for the selection process.

The foams were selected solely on the basis of their flame spread values. Although the smoke values were not considered, the foams selected for further evaluation were among those having the best smoke ratings (Tables 13 and 14.)

Selection of the borderline foams was arbitrary. However, to make certain that no really promising foam was eliminated this early in the selection process, these marginally-performing products were included.

Comments - Although a primary basis for the initial selection of all of the foam candidates was good flame-resistant properties, the ASTM E162 flame spread data showed wide variation. The flame spread indices varied

from a low of 2 to a high of 782 with a mean value of 229. Only six foams had a flame spread index below 25, and about one-half the foams had I_s values of 144 or higher.

These foams constitute a fair representation of the best commercial foams available, and all were reported to have a flame spread rating of 30 or less by the ASTM E84 test (25-foot tunnel). The ASTM E84 test is the standard in the construction industry and is considered to be equivalent to the ASTM E162 test by MSHA. The MSAR data does not support this assumption, and it leaves unanswered the question of which test, E84 or E162, more closely compares with the flame spread of foams under actual mine fire conditions.

Water Immersion Tests

Foam used in mines is usually subjected to both high relative humidity and water; therefore moisture and water must have no deleterious effect. Possible undesirable effects include (1) structural weakening and increased combustibility due to the loss or hydrolysis of flame retardant or other materials from the foam, or (2) increased air permeability due to a reduction of the closed cell content.

The effect of water was determined by immersing 6 inch by 18 inch by 1 inch thick samples of foam in distilled water for a period of 96 hours. After the samples were removed from the water, the drained weight was determined. The samples were then allowed to dry to a constant weight and weight loss, dimension changes, flame spread by E162 and E162-CCC-2, compressive strength and closed cell content were measured. These results were compared with untreated samples.

Nine samples of each formulation (a total of one-half cubic foot) were subjected to water immersion. Each sample was separated with a wire mesh divider for good exposure, and each formulation was tested in separate water chambers to prevent undesirable component interaction or exchange. The phenolic foam candidate (Item 26) was the only exception to this procedure because of a shortage of sample.

ASTM E162 Tests - Four samples of each of the candidate foams were subjected to the ASTM E162 radiant panel test after water immersion. The results obtained are shown in Table 15 along with the mean and standard deviation. The average results are summarized in Table 16 where they are compared with the averages of previous data on virgin foams.

In general, the flame spread index, the inches burned, and peak smoke values did not change significantly. The smoke area values did increase slightly for eight of the 16 foams (Items 11, 19, 21, 22, 23, 24, 25 and 26), but the reasons for the smoke area increase are not clear, nor is the magnitude of the increase considered significant.

TABLE 15

ASTM E162 Radiant panel data after water immersion

Sample 1676-	Q	F	Is	In burned	Smoke Peak	Smoke Area	Sample 1676-	Q	F	Is	In burned	Smoke Peak	Smoke Area
46 - 5	4.9	22.3	108	6	13	2720	46 - 13	5.3	9.2	49	7	11	ND
Item 19	5.7	7.2	41	7	ND	ND	Item 21	4.9	8.4	41	7	11	2550
	4.9	6.1	30	ND	12	2200		4.9	11.3	55	8	13	2400
	6.2	5.5	34	6	11	2230		5.0	7.4	37	8	9	2150
Avg	5.4	10.2	53	6.3	12.0	2383	Avg	5.0	9.1	46	7.5	11.0	2367
Std dev	0.6	8.0	37	0.6	1.0	292	Std dev	0.2	1.6	8	0.6	1.6	202
46 - 7	4.7	3.7	17	4	13	ND	48-1	7.6	12.5	95	8	12	1880
Item 23	4.5	10.3	47	6	13	2550	Item 17	5.7	1.7	11	5	12	1270
	3.7	9.3	35	6	12	2230		5.4	13.2	71	7	13	2050
	3.9	8.7	34	6	14	2240		5.7	8.4	47	8	11	1800
Avg	4.2	8.0	33	5.5	13.0	2340	Avg	6.1	8.9	56	7.0	12.0	1750
Std dev	0.5	2.9	12	1.0	0.8	182	Std dev	1.0	5.3	36	1.4	0.8	337
46 - 8	5.7	32.7	185	11	28	2880	48 - 6	6.3	1.9	12	4	11	ND
Item 22	10.7	47.4	507	10	30	3570	Item 15	5.7	1.7	9	3	14	1630
	5.3	35.1	187	11	25	2250		5.0	1.6	8	3	40	3030
	3.7	27.1	101	11	29	3560		5.7	1.7	10	3	11	1740
Avg	6.4	35.6	245	10.8	28.0	3065	Avg	5.7	1.7	10	3.3	19.0	2133
Std dev	3.0	8.6	179	0.5	2.2	632	Std dev	0.5	0.2	2	0.5	14.1	778
46 -10	4.9	11.4	55	6	16	3280	48 - 7	4.1	2.0	8	3	10	1330
Item 11	4.4	53.1	232	6	19	3380	Item 14	4.5	1.7	8	3	14	1790
	5.2	19.8	102	6	16	3440		4.1	8.9	36	6	12	1740
	5.4	10.0	54	7	19	2900		4.4	2.3	10	3	13	2300
Avg	4.9	23.6	111	6.3	17.5	3250	Avg	4.3	3.7	15	3.8	12.3	1790
Std dev	0.4	20.1	84	0.5	1.7	242	Std dev	0.2	3.5	14	1.5	1.7	398

TABLE 15 (cont)

ASTM E162 Radiant panel data after water immersion

Sample 1676-	Q	F	Is	In burned	Smoke Peak	Smoke Area
48 - 8 Item 18	6.0	7.7	46	8	11	1320
	4.9	7.0	34	7	9	1660
	5.0	12.0	60	9	12	2170
	6.5	33.2	215	9	14	2240
Avg	5.6	15.0	89	8.3	11.5	1848
Std dev	0.8	12.4	85	1.0	2.1	436
48 - 9 Item 9	3.9	42.0	163	9	24	2400
	2.9	56.4	165	17	27	2560
	3.2	52.1	169	17	26	2030
	3.2	63.7	206	17	27	2440
Avg	3.3	53.5	176	15.0	26.0	2358
Std dev	0.4	9.1	20	4.0	1.4	229
48 - 11 Item 4	5.7	22.4	127	11	18	2730
	4.9	25.7	125	10	26	2640
	5.7	32.3	183	11	23	2880
	5.7	30.4	172	10	24	1540
Avg	5.5	27.7	152	10.5	22.8	2448
Std dev	0.4	4.5	30	0.6	3.4	613
48 - 12 Item 5	2.3	1.0	2	0	8	1270
	2.4	1.0	2	1	8	1400
	2.3	1.0	2	1	8	1290
	2.9	1.0	3	1	17	2000
Avg	2.5	1.0	3	0.8	10.3	1490
Std dev	0.3	0.0	0	0.5	4.5	345

Sample 1676-	Q	F	Is	In burned	Smoke Peak	Smoke Area
50 - 2 Item 24	9.2	9.6	89	14	7	8490
	8.1	9.8	79	14	6	7290
	9.7	10.4	101	15	7	10,010
	6.5	10.9	71	-	9	13,300
Avg	8.4	10.2	85	14.3	7.3	9773
Std dev	1.4	0.6	13	0.6	1.3	2602
50 - 3 Item 25	4.9	1.0	5	0	-	3950
	4.1	1.0	4	0	-	5290
	6.8	1.0	7	0	1	3620
	4.1	1.0	4	0	4	6320
Avg	4.9	1.0	5	0	2.5	4795
Std dev	1.3	0.0	1	0	2.1	1247
50 - 4 Item 27	7.0	11.5	80	9	30	4700
	6.8	7.9	54	7	20	2710
	5.4	7.2	38	6	13	2440
	5.7	7.5	43	7	21	4650
Avg	6.2	8.5	54	7.3	21.0	3625
Std dev	0.8	2.0	19	1.3	7.0	1218
50 - 5 Item 26	3.2	1.5	5	3	1.5	2975
Avg	3.2	1.5	5	3	1.5	2975
Std dev	NM	NM	NM	NM	NM	NM

Note: NM = Not meaningful

TABLE 16

Comparison of test data for virgin (before) and water-immersed (after) samples by ASTM E162

Item no	Sample 1676-	Q		F		Is		In burned		Peak smoke		Smoke area	
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
4	48-11	4.8	5.5	30.3	27.5	144	152	11.4	10.5	24.6	22.8	2814	2448
5	48-12	2.4	2.5	1.0	1.0	2	3	1.0	0.8	11.0	10.3	1100	1490
9	48-9	1.9	3.3	59.7	53.5	112	176	11.3	15.0	22.1	26.0	1806	2358
11	46-10	3.5	4.9	19.8	23.6	68	111	6.5	6.3	18.8	17.5	2329	3250
14	48-7	4.2	4.3	2.5	3.7	10	15	3.5	3.8	11.5	12.3	1449	1790
15	48-6	5.7	5.7	2.2	1.7	12	10	3.0	3.3	16.1	19.0	1595	2133
17	48-1	5.1	6.1	12.4	8.9	65	56	4.0	7.0	13.0	12.0	1770	1750
18	48-8	7.3	5.6	9.4	15.0	66	89	4.5	8.3	11.5	11.5	1912	1848
19	46-5	5.6	5.4	7.4	10.2	41	53	3.0	6.3	13.9	12.0	1816	2383
21	46-13	5.5	5.0	15.4	9.1	83	46	5.5	7.5	13.1	11.0	1860	2367
22	46-8	5.7	6.4	35.5	35.6	176	245	10.0	10.8	27.3	28.0	2218	3065
23	46-7	4.9	4.2	2.7	8.0	13	33	3.0	5.5	12.0	13.0	1533	2340
24	50-2	8.4	8.4	8.9	10.2	75	85	14.0	14.3	7.3	7.3	7427	9773
25	50-3	6.6	4.9	2.4	1.0	16	5	3.0	0	3.0	2.5	3138	4795
26	50-5	2.4	3.2	1.0	1.5	3	5	<3	3	0	1.5	0	2975
27	50-4	6.9	6.2	14.0	8.5	97	54	9.3	7.3	32.0	21.0	3560	3625

TABLE 17

E162-CCC-2 Modified radiant panel data after water immersion

Sample 1676-	Q	F	Is	In burned	Smoke Peak	Smoke Area	Sample 1676-	Q	F	Is	In burned	Smoke Peak	Smoke Area
46 - 5	8.8	251	2199	18	65	4720	46 - 13	9.1	279	2688	18	64	(3200+)
Item 19	8.2	251	2052	18	60	5800	Item 21	8.6	301	2592	18	54	3890
	7.4	251	1867	18	65	4520		8.8	301	2637	18	66	(2990+)
	9.1	251	2271	18	60	4940		10.1	301	3031	18	63	5380
Avg	8.4	251	2097	18	62.5	4995	Avg	9.2	296	2737	18	61.8	4635
Std dev	0.7	0	179	0	2.9	563	Std dev	0.7	11	200	0	5.3	1054
46 - 7	5.3	251	1319	18	53	5050	48-1	9.1	201	1810	18	60	4550
Item 23	7.6	251	1905	18	56	6080	Item 17	10.2	201	2044	18	55	4770
	6.1	251	1539	18	62	5790		9.3	201	1869	18	55	4420
	7.7	218	1684	18	52	5040		8.6	201	1723	18	55	4500
Avg	6.7	243	1612	18	56.0	5490	Avg	9.3	201	1862	18	56.3	4560
Std dev	1.2	17	246	0	4.5	527	Std dev	0.7	0	136	0	2.5	150
46 - 8	12.7	251	3188	18	74	6450	48 - 6	5.6	251	1392	18	44	ND
Item 22	10.2	251	2560	18	74	7210	Item 15	6.1	251	1539	18	44	5560
	10.6	168	1777	18	81	6770		6.6	251	1649	18	43	(3920+)
	10.8	159	1721	18	73	6670		5.6	251	1392	18	44	5560
Avg	11.1	207	2312	18	75.5	6775	Avg	6.0	251	1493	18	43.8	5560
Std dev	1.1	51	699	0	3.7	319	Std dev	0.5	0	125	0	0.5	0
46 -10	9.8	218	2129	18	50	5000	48 - 7	6.9	251	1722	18	55	4460
Item 11	6.4	218	1398	18	46	(3330+)	Item 14	6.7	168	1125	18	51	3960
	8.0	168	1346	18	49	4270		6.7	251	1684	18	56	4730
	9.8	168	1640	18	57	5130		6.9	251	1722	18	50	ND
Avg	8.5	193	1628	18	50.5	4867	Avg	6.8	230	1563	18	53.0	4383
Std dev	1.6	29	358	0	4.7	350	Std dev	0.1	42	293	0	2.9	391

TABLE 17 (cont)

E162-CCC-2 Modified radiant panel data after water immersion

Sample 1676-	Q	F	Is	In burned	Smoke Peak	Smoke Area
48 - 8 Item 18	11.7	351	4100	18	61	3970
	13.1	351	4612	18	64	(3850+)
	11.5	351	4048	18	61	5500
	11.3	351	3946	18	63	5580
Avg	11.9	351	4177	18	62.3	5017
Std dev	0.8	0	297	0	1.5	907
48 - 9 Item 9	6.1	151	926	18	27	ND
	5.3	128	675	18	30	3340
	5.1	159	814	18	31	3390
	5.4	159	860	18	29	3680
Avg	5.5	149	819	18	29.3	3470
Std dev	0.5	15	106	0	1.7	184
48 - 11 Item 4	9.5	226	2145	18	65	6930
	9.3	204	1909	18	70	6660
	10.8	168	1811	18	72	7070
	8.3	168	1395	18	68	7350
Avg	9.5	192	1815	18	68.8	7003
Std dev	1.0	29	313	0	3.0	287
48 - 12 Item 5	0.4	101	37	3	44	4340
	0.9	101	88	3	45	3860
	0.7	101	74	3	33	3510
	0.4	101	44	3	42	2650
Avg	0.6	101	61	3.0	41.0	3590
Std dev	0.2	0	24	0	5.5	713

Sample 1676-	Q	F	Is	In burned	Smoke Peak	Smoke Area
50 - 2 Item 24	9.0	11.5	104	12	6	6350
	8.5	11.4	96	12	7	7300
	10.7	11.6	124	12	7	6280
	6.6	13.5	88	12	6	3400
Avg	8.7	12.0	103	12	6.5	5833
Std dev	1.7	1.0	15	0	0.6	1087
50 - 3 Item 25	1.0	6.5	7	7	9	6370
	1.2	6.5	8	7	8	7400
	2.2	4.7	10	7	6	6270
	2.6	5.3	14	7	8	6350
Avg	1.8	5.8	9	7	7.8	6598
Std dev	0.8	0.9	3	0	1.3	537
50 - 4 Item 27	7.7	115	894	18	73	(3540+)
	11.7	286	3340	18	82	7110
	8.8	168	1469	18	85	8580
	11.7	154	1796	18	59	(3430+)
Avg	10.0	181	1875	18	74.8	7845
Std dev	2.0	74	1046	0	11.7	1039
50 - 5 Item 26	2.2	1.0	2	3	0	4090
Avg	2.2	1.0	2	3	1.5	4090
Std dev	NM	NM	NM	NM	NM	NM

Note: ND = No data
NM = Not meaningful

TABLE 18

Comparison of test data for virgin (before) and water-immersed samples by E162-CCC-2

Item no	Sample 1676-	Q		F		Is		In burned		Peak smoke		Smoke area	
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
4	48-11	8.0	9.5	171	192	1367	1815	18	18	68.4	68.8	6300	7003
5	48-12	0.4	0.6	101	101	39	61	3	3	32.1	41.0	2468	3590
9	48-9	4.0	5.5	163	149	645	819	18	18	34.8	29.3	3118	3470
11	46-10	4.6	8.5	170	193	781	1628	18	18	53.5	50.5	4581	4867
14	48-7	4.5	6.8	156	230	696	1563	18	18	43.1	53.0	3210	4383
15	48-6	5.7	6.0	218	251	1245	1493	18	18	37.9	43.8	3738	5560
17	48-1	8.0	9.3	193	201	1551	1862	18	18	60.9	56.3	5280	4560
18	48-8	9.5	11.9	301	351	2845	4177	18	18	67.5	62.3	4587	5017
19	46-5	9.1	8.4	351	251	3185	2097	18	18	53.8	62.5	4233	4995
21	46-13	6.2	9.2	351	296	2165	2737	18	18	56.5	61.8	3335	4635
22	46-8	9.7	11.1	101	207	981	2312	18	18	75.6	75.5	5600	6775
23	46-7	5.8	6.7	301	243	1748	1612	18	18	43.8	56.0	3253	5490
24	50-2	40.2	8.7	13	12	529	103	12	12	6.6	6.5	8025	5833
25	50-3	0.7	1.8	1	6	1	9	1	7	5.5	7.8	8400	6598
26	50-5	2.8	2.2	1	1	3	2	<3	3	2	0	4970+	4090
27	50-4	10.0	10.0	120	181	1219	1875	15	18	71.8	74.8	5243	7845

E162-CCC-2 Tests - Four samples of each candidate foam were also tested by the E162-CCC-2 radiant panel after being thoroughly dried. These data are shown in Table 17 along with the mean and standard deviation. The data are summarized in Table 18 and compared with the values obtained with virgin foam.

The flame spread index values for Items 11, 14, and 18 seemed to have increased significantly after the water immersion. The precision of the Is values is less at the higher values, so the significance of these higher values is not clear. It may indicate, however, the beginning of a harmful effect. Certainly these foams should be viewed with suspicion. The results for Item 24, which decreased significantly, cannot be explained and are suspect.

The increase in some of the peak smoke values was also rather large, but once again it is hard to properly evaluate these high smoke values. In general, these changes in the smoke are not deemed to be critical.

Changes in Weight - The foam samples were weighed prior to the 96 hour immersion in water, and then reweighed 15-30 minutes and 48 hours after removing them from the water. Initially, a 96 hour weighing was also made, but was abandoned when it routinely showed no additional weight loss.

The 15-30 minute weight gives a picture of how much water was actually absorbed/adsorbed by the foam. The 48 hour weight was designed to show if any significant amount of material was extracted. The data, along with the mean and standard deviation, are shown in Table 19 and are summarized in Table 20.

Most of the foams showed a 20-47 gram weight gain at the 15-30 minutes weighing. This is equivalent to a 39-72% increase in weight. Since the silicone and Hypol foams (Items 24 and 25) were attached to cement asbestos boards, the % increase is not meaningful.

The silicone foam (Item 24) picked up about twice the weight of water as most of the other foams. The Hypol-based foam (Item 25) and the phenolic foam (Item 26) picked up over 600 grams of water. These two foams are open celled and apparently hydrophilic. Furthermore, both the Hypol and phenolic foams seemed to be much weaker when wet. The Hypol foam could hardly be removed from the water without tearing. Whether the apparent weakness when they are wet is structural or due to the weight of the large pickup of water is not certain, but the loss in weight of the Hypol upon drying suggests that its weakness might be due to removal of material from the foam.

TABLE 19

Effect of water immersion on weight

Sample 1676-	Weight, g						
		15-30 min after			48 hr after		
	Before	After	Gain	%	After	Gain	%
46-5*	57.8	97.2	39.4	68.2	57.7	-0.1	-0.17
Item 19	57.5	98.3	40.8	71.0	57.2	-0.3	-0.52
	58.3	93.6	35.3	60.5	58.1	-0.2	-0.34
	58.1	101.0	42.9	73.8	58.0	-0.1	-0.17
	57.8	97.5	39.7	68.7	57.5	-0.3	-0.52
	57.2	97.2	40.0	69.9	57.0	-0.2	-0.34
	58.4	99.9	41.5	71.1	58.2	-0.2	-0.34
	57.5	99.7	42.2	73.4	57.0	-0.5	-0.87
	59.4	111.0	51.6	86.7	59.1	-0.3	-0.51
Avg	NM	NM	41.5	71.5	NM	-0.2	-0.42
Std dev	NM	NM	4.4	7.0	NM	0.1	0.21
46-7	50.8	80.3	29.5	58.1	50.9	0.1	0.20
Item 23	55.2	90.0	34.8	63.0	55.2	0.0	0.00
	56.7	90.0	33.3	58.7	56.8	0.1	0.18
	56.7	87.2	30.5	53.8	56.9	0.2	0.35
	56.5	89.3	32.8	58.1	56.4	-0.1	-0.18
	58.7	92.6	33.9	57.8	58.9	0.2	0.34
	57.2	90.8	33.6	58.7	57.5	0.3	0.52
	56.0	89.8	33.8	60.4	55.9	-0.1	-0.18
	64.6	109.2	44.6	69.0	64.9	0.3	0.46
Avg	NM	NM	34.1	59.7	NM	0.1	0.19
Std dev	NM	NM	4.3	4.3	NM	0.2	0.26

Sample 1676-	Weight, g						
		15-30 min after			48 hr after		
	Before	After	Gain	%	After	Gain	%
46-8*	51.6	71.5	19.9	38.6	51.6	0.0	0.00
Item 22	56.2	78.5	22.3	39.7	56.2	0.0	0.00
	55.7	83.3	27.6	49.6	55.7	0.0	0.00
	54.7	82.2	27.5	50.3	54.8	0.1	0.18
	51.5	79.5	28.0	54.4	51.5	0.0	0.00
	51.9	76.8	24.9	48.0	52.0	0.1	0.19
	49.9	71.8	21.9	43.9	49.9	0.0	0.00
	58.1	81.2	23.1	39.8	58.3	0.2	0.34
	63.5	90.0	26.5	41.7	63.4	-0.1	-0.15
Avg	NM	NM	24.6	45.1	NM	0.0	0.06
Std dev	NM	NM	2.9	5.6	NM	0.1	0.15
46-10	57.1	88.1	31.0	54.3	56.9	-0.2	-0.35
Item 11	55.5	80.1	24.9	45.1	55.2	0.0	0.00
	55.5	85.5	30.0	54.1	55.3	-0.2	-0.36
	53.8	86.6	32.8	61.0	53.5	-0.3	-0.56
	55.1	84.1	29.0	52.6	54.8	-0.3	-0.54
	52.0	80.0	28.0	53.8	51.8	-0.2	-0.38
	58.4	86.2	27.8	47.6	58.0	-0.4	-0.68
	54.9	80.0	25.1	45.7	54.8	-0.1	-0.18
	64.8	102.9	38.1	58.8	64.5	-0.3	-0.46
Avg	NM	NM	29.6	52.6	NM	-0.2	-0.39
Std dev	NM	NM	4.1	5.5	NM	0.1	0.21

TABLE 19 (cont)

Effect of water immersion on weight

Sample 1676-	Weight, g						
		15-30 min after			48 hr after		
	Before	After	Gain	%	After	Gain	%
46-13	61.7	97.0	35.3	57.2	61.8	0.1	0.16
Item 21	53.9	89.9	36.0	66.8	54.1	0.2	0.37
	60.6	96.0	35.4	58.4	60.7	0.1	0.17
	56.8	92.5	35.7	62.9	57.0	0.2	0.35
	50.3	87.0	36.7	73.0	50.4	0.1	0.20
	58.2	95.0	36.8	63.2	58.3	0.1	0.17
	50.7	88.0	37.3	73.6	50.8	0.1	0.20
	53.8	88.5	34.7	64.5	53.7	-0.1	-0.19
	72.7	122.0	49.3	67.8	72.9	0.2	0.28
Avg	NM	NM	37.5	65.3	NM	0.1	0.19
Std dev	NM	NM	4.5	5.7	NM	0.1	0.16
48-1 *	54.7	77.8	23.1	42.2	54.5	-0.2	-0.37
Item 17	51.4	73.7	22.3	43.4	51.0	-0.4	-0.78
	51.0	73.8	22.8	44.7	51.0	0.0	0.00
	54.9	75.6	20.7	37.7	54.8	-0.1	-0.18
	53.8	77.3	23.5	43.7	53.5	-0.3	-0.56
	53.4	73.3	19.9	37.3	53.1	-0.3	-0.56
	51.4	70.5	19.1	37.2	51.3	-0.1	-0.19
	52.0	70.6	18.6	35.8	52.0	0.0	0.00
	61.7	80.0	18.3	29.7	61.6	-0.1	-0.16
Avg	NM	NM	20.9	39.1	NM	-0.2	-0.31
Std dev	NM	NM	2.0	4.9	NM	0.1	0.27

Sample 1676-	Weight, g						
		15-30 min after			48 hr after		
	Before	After	Gain	%	After	Gain	%
48-6	73.7	101.8	28.1	38.1	73.7	0.0	0.00
Item 15	73.7	100.6	26.9	36.5	73.7	0.0	0.00
	76.7	105.9	29.2	38.1	76.4	-0.3	-0.39
	70.1	96.4	26.3	37.5	70.0	-0.1	-0.14
	70.6	98.8	28.2	39.9	70.6	0.0	0.00
	72.9	104.0	31.1	42.7	72.9	0.0	0.00
	72.9	100.4	27.5	37.7	73.0	0.1	0.14
	71.5	97.9	26.4	36.9	71.6	0.1	0.14
	73.3	113.3	40.0	54.6	73.6	0.3	0.41
Avg	NM	NM	29.3	40.2	NM	0.0	0.02
Std dev	NM	NM	4.3	5.7	NM	0.2	0.22
48-7	56.2	80.0	23.8	42.3	56.0	-0.2	-0.36
Item 14	53.7	81.0	27.3	50.8	53.7	0.0	0.00
	58.0	84.8	26.8	46.2	58.0	0.0	0.00
	56.4	85.0	28.6	50.7	56.3	-0.1	-0.18
	56.2	84.6	28.4	50.5	56.0	-0.2	-0.36
	53.6	80.5	26.9	50.2	53.6	0.0	0.00
	54.3	81.5	27.2	50.1	54.3	0.0	0.00
	54.0	82.8	28.8	53.3	53.8	-0.2	-0.37
	60.4	99.2	38.8	64.2	60.4	0.0	0.00
Avg	NM	NM	28.5	50.9	NM	-0.1	-0.14
Std dev	NM	NM	4.1	5.9	NM	0.1	0.18

TABLE 19 (cont)

Effect of water immersion on weight

Sample 1676-	Weight, g Before	15-30 min after: After	Gain	%	48 hr after: After	Gain	%
48-8	58.6	101.0	42.4	72.4	58.4	-0.2	-0.34
Item 18	65.0	108.0	43.0	66.2	64.7	-0.3	-0.46
	65.1	107.6	42.5	65.3	65.2	0.1	0.15
	64.5	106.3	41.8	64.8	64.5	0.0	0.00
	57.3	100.0	42.7	74.5	57.2	-0.1	-0.18
	52.4	90.5	38.1	72.7	52.3	-0.1	-0.19
	59.6	104.8	45.2	75.8	59.3	-0.3	-0.50
	58.4	102.8	44.4	76.0	58.3	-0.1	-0.17
	66.1	115.3	49.2	74.4	66.1	0.0	0.05
Avg	NM	NM	43.3	71.3	NM	-0.1	-0.15
Std dev	NM	NM	3.0	4.6	NM	0.1	0.25
48-9	64.8	117.2	52.4	80.9	64.2	-0.6	-0.93
Item 9	65.9	117.5	51.6	78.3	65.3	-0.6	-0.91
	67.8	122.2	54.4	80.2	67.0	-0.8	-1.18
	67.7	110.0	42.3	62.5	66.6	-1.1	-1.62
	66.5	104.5	38.0	57.1	65.6	-0.9	-1.35
	63.2	104.0	40.8	64.6	62.1	-1.1	-1.74
	65.1	119.4	54.3	83.4	64.7	-0.4	-0.61
	66.2	101.7	35.5	53.6	65.5	-0.7	-1.06
	65.3	117.7	52.4	80.2	64.4	-0.9	-1.38
Avg	NM	NM	46.9	71.2	NM	-0.8	-1.20
Std dev	NM	NM	7.6	11.6	NM	0.2	0.36

Sample 1676-	Weight, g Before	15-30 min after: After	Gain	%	48 hr after: After	Gain	%
48-11	56.1	88.3	32.2	57.4	56.4	0.3	0.53
Item 4	58.1	95.4	37.3	64.2	58.1	0.0	0.00
	60.5	97.4	36.9	61.0	60.3	-0.2	-0.33
	56.5	91.8	35.3	62.5	56.6	0.1	0.18
	57.0	90.8	33.8	59.3	56.8	-0.2	-0.35
	56.5	87.2	30.7	54.3	56.5	0.0	0.00
	58.5	89.8	31.3	53.5	58.3	-0.2	-0.34
	58.3	93.5	35.2	60.4	58.2	-0.1	-0.17
	51.7	84.3	32.6	63.1	51.6	-0.1	-0.19
Avg	NM	NM	33.9	59.5	NM	0.0	-0.08
Std dev	NM	NM	2.4	3.8	NM	0.2	0.29
48-12	52.4	78.0	25.6	48.9	52.2	-0.2	-0.38
Item 5	52.1	83.0	30.9	59.3	52.0	-0.1	-0.19
	55.5	83.8	28.3	51.0	55.5	0.0	0.00
	52.8	82.0	29.2	55.3	52.6	-0.2	-0.38
	54.7	84.0	29.3	53.6	54.6	-0.1	-0.18
	51.6	77.5	25.9	50.2	51.2	-0.4	-0.78
	53.1	79.7	26.6	50.1	52.9	-0.2	-0.38
	45.5	68.0	22.5	49.5	45.4	-0.1	-0.22
	58.2	95.8	37.6	64.6	57.9	-0.3	-0.52
Avg	NM	NM	28.4	53.6	NM	-0.2	-0.34
Std dev	NM	NM	4.2	5.3	NM	0.1	0.22

TABLE 19 (cont)

Effect of water immersion on weight

Sample 1676-	Weight, g Before	15-30 min after: After	Gain	%	48 hr after: After	Gain	%
50-2** Item 24	800	880	80	Not Meaningful	797	-3	Not Meaningful
	805	892	87		804	-1	
	747	832	85		744	-3	
	793	876	83		791	-2	
	789	879	90		788	-1	
	748	829	81		748	0	
	785	870	85		784	-1	
	728	805	77		727	-1	
Avg	NM	NM	83.5		NM	-1.5	
Std dev	NM	NM	4.1		NM	1.1	
50-3*** ** Item 25	761	1400	639		734	-27	
	787	1484	697		758	-29	
	843	1605	762		806	-37	
	932	1884	952		887	-45	
	855	1645	790		821	-34	
	942	1873	931		903	-39	
	1016	2054	1038		973	-43	
	940	1848	908		901	-39	
Avg	NM	NM	840		NM	-37	
Std dev	NM	NM	138		NM	6.3	

Sample 1676-	Weight, g Before	15-30 min after: After	Gain	%	48 hr after: After	Gain	%
50-4 Item 27	67.7	100.9	33.2	49.0	67.1	-0.6	-0.89
	64.7	94.0	29.3	45.3	64.4	-0.3	-0.46
	57.8	87.8	30.0	51.9	57.4	-0.4	-0.69
	61.0	95.9	34.9	57.2	60.2	-0.8	-1.31
	61.7	97.2	35.5	57.5	61.0	-0.7	-1.13
	58.6	88.9	30.3	51.7	58.2	-0.4	-0.68
	57.5	88.9	31.4	54.6	57.0	-0.5	-0.87
	59.5	92.1	32.6	54.8	59.3	-0.2	-0.34
	63.3	108.2	44.9	70.9	62.8	-0.5	-0.79
Avg	NM	NM	33.6	54.8	NM	-0.5	-0.80
Std dev	NM	NM	4.8	7.2	NM	0.2	0.30
					96 hr drying time		
50-5 Item 26	24.0	455.0	431.0	1796	165.0	141.0	588
	76.7	779.0	702.3	916	340.0	263.3	474
	56.4	809.0	752.6	1334	347.5	291.1	516
Avg	NM	NM	628.6	1349	NM	231.8	526
Std dev	NM	NM	173.0	440	NM	79.9	58
		24 hr drying time			1 mo drying time		
	24.0	25.0	1.0	104	19.3	-4.7	-20
	76.7	127.4	50.7	166	63.4	-13.3	-17
	56.4	129.9	73.5	230	50.3	- 6.1	-11
Avg	NM	NM	41.7	167	NM	- 8.0	-16
Std dev	NM	NM	37.1	63	NM	4.6	5

* 24 Hr drying time

** Foam samples or cement asbestos board

*** Sample still wet at 48 hr

Note: NM = Not meaningful

TABLE 20

SUMMARY - Effect of water immersion on weight

Item no	Sample 1676-	Weight increase, g 15-30 min After	 48 hr After	Weight increase, % 15-30 min After	 48 hr After
4	48-11	33.9	0.0	59.5	-0.08
5	48-12	28.4	-0.2	53.6	-0.34
9	48-9	46.9	-0.8	71.2	-1.20
11	46-10	29.6	-0.2	52.6	-0.39
14	48-7	28.5	-0.1	50.9	-0.14
15	48-6	29.3	0.0	40.2	0.02
17*	48-1	20.9	-0.2	39.1	-0.31
18	48-8	43.3	-0.1	71.3	-0.15
19*	46-5	41.5	-0.2	71.5	-0.42
21	46-13	37.5	0.1	65.3	0.19
22*	46-8	24.6	0.0	45.1	0.06
23	46-7	34.1	0.1	59.7	0.19
24**	50-2	83.5	-1.5	NM	NM
25** ***	50-3	840	-37	NM	NM
26	50-5	629	232 (96 hr) -8.0 (1 mo)	1349	526 (96 hr) -16 (1 mo)
27	50-4	33.6	-0.5	54.8	-0.80

Notes:
- * 24 hour drying time
- ** Sample on cement asbestos board
- *** Sample still wet after 48 hours
- NM Not meaningful

The phenolic foam (Item 26) not only picked up a lot of water, but it was also difficult to dry. It was still wet after 10 days, so the one month weight was taken as the final dry weight.

A slight gain in weight from adsorbed or absorbed moisture would not appear to cause any practical problems in the use of the foam as a sealant unless the increase in weight caused the foam to lose its adhesion to the substrate. The importance of adhesion is even more critical if the moisture pick-up weakens the foam as it apparently does with the Hypol foam (Item 25). Thus, the effect of water pick-up on the adhesion and strength of Hypol and phenolic foams should be checked further before using them in mines.

The urethane foams showed little weight loss on drying, indicating no significant leaching of material. The final weights were usually within one gram of the original weight. The silicone foam (Item 24) lost a bit more weight than did most urethane foams. The phenolic foam (Item 26) lost about 16% of its weight, suggesting that something was removed. The Hypol foam (Item 25) lost the most weight, indicating the probable loss of some of the solids with which this foam is loaded. Foams losing a significant amount of weight should be checked for even longer range effects on their ability to seal a stopping and resist flame propagation.

Surface Area - The surface area of the foams was measured before and after the water immersion test. No measurements were made on Items 24 and 25 because their movements were restricted by the cement asbestos board to which they were attached. The data obtained are shown in Table 21 along with the average and standard deviations of the change in area. These data are summarized in Table 22.

The % area changes were negligible for all but Items 11 and 26. The unusually high shrinkage of Item 11 might lead to ultimate failure by splitting on a substrate. This can only be determined by an actual field test. Item 26 might also suffer the same fate because the phenolic is more brittle than the urethane foams.

Effect on Closed Cell and Foam Density - The % closed cell and densities were determined on foam samples both before and after water immersion. These data are shown in Table 23 along with the average and standard deviation. The data are summarized in Table 24.

Most of the foams are essentially closed cell. The range of 88-99% is typical of what one would expect to find. The low closed cell content of the silicone and Hypol samples, (Items 24 and 25) are typical of flexible foams. If a flexible foam contains a high percentage of closed cells, it is likely to shrink at or below room temperature. The open-celled nature of Item 26 is historically typical of flexible and phenolic foams, but both W. R. Grace and Reichhold claim they can make their foam closed cell.

TABLE 21

Effect of water immersion on surface area

Sample 1676-	Area, in^2 Before	After	Area Increase in^2	%	Sample 1676-	Area, in^2 Before	After	Area Increase in^2	%	Sample 1676-	Area, in^2 Before	After	Area Increase in^2	%
46 - 5	106.94	107.67	0.73	0.68	46 - 10	111.60	108.04	-3.56	-3.19	48 - 6	110.45	111.00	0.55	0.50
Item 19	106.39	107.49	1.10	1.03	Item 11	111.60	108.81	-2.79	-2.50	Item 15	109.34	110.08	0.74	0.68
	106.39	107.12	0.73	0.69		109.74	108.25	-1.49	-1.36		109.70	110.07	0.37	0.34
	106.94	107.67	0.73	0.68		109.74	108.44	-1.30	-1.18		109.72	110.26	0.54	0.49
	106.94	107.68	0.74	0.69		111.60	108.04	-3.56	-3.19		109.88	110.25	0.37	0.34
	107.85	108.41	0.56	0.52		112.50	109.40	-3.10	-2.76		109.72	111.00	1.28	1.17
	107.30	107.85	0.55	0.51		111.60	109.00	-2.60	-2.33		109.70	110.25	0.55	0.50
	107.68	107.12	-0.56	-0.52		111.60	109.00	-2.60	-2.33		109.72	110.62	0.90	0.82
	108.61	108.96	0.35	0.32		112.20	108.81	-3.39	-3.02		111.81	ND	ND	ND
Avg	NM	NM	0.55	0.51	Avf	NM	NM	-2.71	-2.43	Avg	NM	NM	0.66	0.61
Std dev	NM	NM	0.46	0.43	Std dev	NM	NM	0.83	0.74	Std dev	NM	NM	0.31	0.28
46 - 7	112.87	113.24	0.37	0.33	46 - 13	108.22	107.49	-0.73	-0.67	48 - 7	111.75	112.87	1.12	1.00
Item 23	110.64	112.49	1.85	1.67	Item 21	109.33	109.52	0.19	0.17	Item 14	110.82	111.37	0.55	0.50
	112.11	112.87	0.76	0.68		108.23	107.31	-0.92	-0.85		110.54	110.82	0.28	0.25
	112.87	112.87	0.00	0.00		109.15	109.15	0.00	0.00		112.49	112.87	0.38	0.34
	112.87	112.87	0.00	0.00		109.87	110.25	0.38	0.35		110.35	111.00	0.65	0.59
	111.00	111.00	0.00	0.00		108.22	108.41	0.19	0.18		111.37	112.87	1.50	1.35
	112.87	113.24	0.37	0.33		108.22	107.49	-0.73	-0.67		112.49	112.87	0.38	0.34
	112.87	112.87	0.00	0.00		107.86	107.68	-0.18	-0.17		111.00	111.37	0.37	0.33
	112.87	ND	ND	ND		111.56	110.82	-0.74	-0.66		109.72	ND	ND	ND
Avg	NM	NM	0.42	0.38	Avg	NM	NM	-0.28	-0.26	Avg	NM	NM	0.65	0.59
Std dev	NM	NM	0.64	0.58	Std dev	NM	NM	0.50	0.46	Std dev	NM	NM	0.43	0.39
46 - 8	108.41	108.04	-0.37	-0.34	48 - 1	106.58	106.76	0.18	0.17	48 - 8	111.60	111.60	0.00	0.00
Item 22	106.76	106.58	-0.18	-0.17	Item 17	106.01	106.19	0.18	0.17	Item 18	111.00	111.00	0.00	0.00
	109.52	110.25	0.73	0.67		106.03	106.03	0.00	0.00		108.56	109.15	0.59	0.54
	108.77	108.22	-0.55	-0.51		106.93	107.09	0.16	0.15		108.56	110.40	1.84	1.69
	110.25	110.25	0.00	0.00		107.30	107.49	0.19	0.18		111.00	111.60	0.60	0.55
	107.13	107.86	0.73	0.68		106.35	106.16	-0.19	-0.18		111.60	111.60	0.00	0.00
	108.04	108.59	0.55	0.51		108.41	108.41	0.00	0.00		111.00	109.15	-1.85	-1.67
	108.22	108.22	0.00	0.00		105.12	105.49	0.37	0.35		111.00	111.00	0.00	0.00
	109.14	109.70	0.56	0.51		107.49	107.86	0.37	0.35		111.00	108.56	-2.44	-2.20
Avg	NM	NM	0.16	0.15	Avg	NM	NM	0.14	0.13	Avg	NM	NM	-0.14	-0.12
Std dev	NM	NM	0.49	0.45	Std dev	NM	NM	0.18	0.17	Std dev	NM	NM	1.29	1.17

TABLE 21 (cont)

Effect of water immersion on surface area

Sample 1676-	Area, in² Before	Area, in² After	Area Increase in²	Area Increase %
48 - 9 Item 9	106.02	106.12	0.10	0.09
	107.68	107.77	0.09	0.08
	107.13	107.13	0.00	0.00
	107.13	106.95	-0.18	-0.17
	107.49	106.95	-0.54	-0.50
	105.67	106.03	0.36	0.34
	106.76	106.76	0.00	0.00
	107.67	107.67	0.00	0.00
	108.60	108.50	-0.10	-0.09
Avg	NM	NM	-0.03	-0.03
Std dev	NM	NM	0.24	0.23
48 - 11 Item 4	106.38	105.80	-0.58	-0.55
	106.38	105.45	-0.93	-0.87
	106.38	105.80	-0.58	-0.55
	106.38	106.38	0.00	0.00
	106.38	105.80	-0.58	-0.55
	106.38	105.80	-0.58	-0.55
	106.38	106.38	0.00	0.00
	106.38	105.80	-0.58	-0.55
	89.36	88.87	-0.49	-0.55
Avg	NM	NM	-0.48	-0.46
Std dev	NM	NM	0.30	0.28
48 - 12 Item 5	109.15	109.33	0.18	0.16
	108.04	108.23	0.19	0.18
	107.86	108.05	0.19	0.18
	109.52	109.71	0.19	0.17
	109.15	109.15	0.00	0.00
	108.05	108.41	0.36	0.33
	108.23	108.41	0.18	0.17
	109.15	109.33	0.18	0.16
	108.96	109.15	0.19	0.17
Avg	NM	NM	0.18	0.17
Std dev	NM	NM	0.09	0.08

Sample 1676-	Area, in² Before	Area, in² After	Area Increase in²	Area Increase %
50 - 4 Item 27	103.30	102.24	-1.06	-1.03
	102.41	101.53	-0.88	-0.86
	102.77	102.60	-0.17	-0.17
	102.51	102.87	0.36	0.35
	103.12	102.96	-0.16	-0.16
	102.33	101.99	-0.34	-0.33
	104.40	103.68	-0.72	-0.69
	102.60	102.78	0.18	0.18
	103.53	103.50	-0.03	-0.03
Avg	NM	NM	-0.31	-0.30
Std dev	NM	NM	0.48	0.47
50 - 5 Item 26	42.05	41.83	-0.22	-0.52
	83.67	82.30	-1.37	-1.64
	88.82	88.35	-0.47	-0.53
Avg	NM	NM	-0.69	-0.90
Std dev	NM	NM	0.60	0.64

Note: ND = No data
NM = Not meaningful

TABLE 22

Summary

effect of water immersion on surface area

Item no	Sample 1676-	Area Increase In^2	Area Increase %
4	48-11	-0.48	-0.46
5	48-12	0.18	0.17
9	48-9	-0.03	-0.03
11	46-10	-2.71	-2.43
14	48-7	0.65	0.59
15	48-6	0.66	0.61
17	48-1	0.14	0.13
18	48-8	-0.14	-0.12
19	46-5	0.55	0.51
21	46-13	-0.28	-0.26
22	46-8	0.16	0.15
23	46-7	0.42	0.38
26	50-5	-0.69	-0.90
27	50-4	-0.31	-0.30

The foam densities were also typical of what we would expect. The density of Item 24 is higher, but seems to be typical of silicone foams. The high density of Item 25 is a result of the high loading of solids in the foam. The foam almost acts as a carrier for the fire resistant additives.

The most important finding was the fact that water immersion had no significant effect upon either the closed cell content or the density, except for the phenolic foam (Item 26). The decrease in density of the phenolic foam correlates with the weight loss (Table 20). Neither the loss in weight nor the corresponding loss in density altered the excellent flame spread properties of the phenolic foam, however, as was shown in Tables 16 and 18.

Effect On Compressive Properties - The compressive strength at 10% deflection was measured and the modulus was calculated both before and after water immersion. The results are shown in Table 25 along with the average values and the standard deviation. Table 26 summarizes the data.

The compressive strength of Items 4, 11, 17, 18 and 21 decreased slightly, but these changes are relatively minor and of no importance for this foam application.

The low compressive strengths shown for the silicone and Hypol samples (Items 24 and 25) are typical of flexible foams. The low value for phenolic (Item 26) is indicative of a weak foam.

Foams to be used as sealants for stoppings have no fixed requirement for compressive properties, but the general requirement is that the foam have sufficient strength to endure the conditions it will encounter. The compressive properties of all these foams are likely adequate for use on stoppings.

Summary of Effect of Water Immersion - In general, the foams withstood the effects of 96 hour water immersion very well. Most of the observed changes were relatively minor and not sufficient to cause rejection of the foam. Some of the changes, however, might indicate that longer periods of water immersion could cause greater changes. The pertinent data for all tests are summarized in Table 27.

The data do show a few things that concern us, but at this time their significance is not clear. They include:

a) low closed cell contents for Items 24, 25 and 26
b) high weight loss values for Items 25 and possibly 26
c) poor wet strength for Item 25 and possibly 26
d) an increase in the flame spread index for Items 11, 14, 18 and 22 by E162-CCC-2
e) decreased compressive strength for Items 11, 17, 18 and 21.

TABLE 23

Effect of water immersion on closed cell and density

Sample 1676-	% Closed cell Before	% Closed cell After	Density, lbs/ft Before	Density, lbs/ft After	Sample 1676-	% Closed cell Before	% Closed cell After	Density, lbs/ft Before	Density, lbs/ft After	Sample 1676-	% Closed cell Before	% Closed cell After	Density, lbs/ft Before	Density, lbs/ft After
46-5	88.6	92.1	2.05	2.02	46-10	95.3	89.5	2.12	2.06	48-6	91.8	91.8	2.41	2.33
Item 19	92.0	91.1	2.04	2.01	Item 11	95.3	91.5	2.12	2.14	Item 15	93.1	92.2	2.35	2.36
	89.2	92.2	2.04	2.03		95.5	91.9	2.08	2.08		93.1	91.4	2.33	2.33
	87.8	91.3	2.03	2.02		95.8	88.9	2.12	2.14		93.6	91.3	2.36	2.38
	88.6	91.7	2.03	2.01		94.0	91.6	2.13	2.18		98.3	90.3	2.53	2.41
Avg	89.2	91.7	2.04	2.02	Avg	95.2	90.7	2.11	2.12	Avg	94.0	91.4	2.40	2.36
Std dev	1.6	0.5	0.01	0.01	Std dev	0.7	1.4	0.02	0.05	Std dev	2.5	0.7	0.08	0.03
46-7	93.1	91.7	2.12	2.10	46-13	91.0	93.9	2.39	2.34	48-7	90.0	97.0	2.02	2.03
Item 23	92.9	89.9	2.12	2.11	Item 21	89.9	91.2	2.36	2.30	Item 14	91.0	95.1	2.03	2.02
	92.2	94.5	2.12	2.12		94.2	90.4	2.38	2.30		91.7	93.9	2.02	2.03
	92.1	95.2	2.14	2.12		94.2	91.2	2.34	2.31		93.2	99.4	2.04	2.04
	94.6	92.7	2.14	2.08		92.0	84.1	2.37	2.31		94.7	93.4	2.01	1.99
Avg	93.0	92.8	2.13	2.11	Avg	92.3	90.2	2.37	2.31	Avg	92.1	95.8	2.02	2.02
Std dev	1.0	2.1	0.01	0.02	Std dev	1.9	3.6	0.02	0.02	Std dev	1.9	2.5	0.01	0.02
46-8	86.3	93.9	2.13	2.21	48-1	88.6	94.5	2.17	2.26	48-8	97.5	97.2	2.20	2.20
Item 22	90.4	93.2	2.15	2.20	Item 17	87.2	91.2	2.15	2.30	Item 18	94.3	97.0	2.21	2.21
	89.9	93.3	2.17	2.21		89.2	94.5	2.27	2.23		93.8	97.0	2.28	2.15
	90.8	90.2	2.14	2.19		98.5	91.5	2.19	2.21		93.7	97.0	2.19	2.21
	90.3	93.7	2.19	2.23		92.4	96.0	2.23	2.25		94.5	97.0	2.24	2.22
Avg	89.5	92.9	2.16	2.21	Avg	91.2	93.5	2.20	2.25	Avg	94.8	97.0	2.22	2.20
Std dev	1.8	1.5	0.02	0.01	Std dev	4.5	2.1	0.05	0.03	Std dev	1.6	0.1	0.04	0.03

TABLE 23 (cont)

Effect of water immersion on closed cell and density

Sample 1676-	% Closed cell Before	% Closed cell After	Density, lbs/ft Before	Density, lbs/ft After	Sample 1676-	% Closed cell Before	% Closed cell After	Density, lbs/ft Before	Density, lbs/ft After
48-9	87.4	85.1	2.20	2.15	50-2	13.9	No	26.0	No
Item 9	87.0	85.8	2.19	2.15	Item 24	23.9	Samples	26.5	Samples
	88.1	88.9	2.20	2.15		23.1		27.2	
	92.0	89.8	2.26	2.17		28.5		27.1	
	89.3	89.8	2.26	2.16		26.6		27.4	
Avg	88.8	87.9	2.22	2.16	Avg	23.2		26.8	
Std dev	2.0	2.3	0.03	0.01	Std dev	5.6		0.6	
48-11	98.4	96.9	2.18	2.23	50-3	8.7	12.7	14.2	15.4
Item 4	98.7	97.0	2.23	2.20	Item 25	9.9	16.7	13.1	14.6
	100	97.0	2.20	2.19		9.8	9.0	14.0	15.1
	98.3	97.0	2.18	2.18		9.9	9.2	13.4	14.5
	97.8	97.0	2.20	2.20		8.8	13.0	13.1	14.3
Avg	98.6	97.0	2.20	2.20	Avg	9.4	12.1	13.6	14.8
Std dev	0.8	0.0	0.02	0.02	Std dev	0.6	3.1	0.5	0.5
48-12	89.8	87.1	2.05	1.94	50-5	1.1	0.0	2.37	2.39
Item 5	93.2	91.5	2.02	1.94	Item 26	0.3	1.2	2.50	1.48
	94.8	91.1	2.02	1.96		0.8	1.2	2.45	1.54
	89.8	92.6	2.04	1.94		0.5	0.2	2.34	2.25
	96.4	89.0	2.00	1.93		0.4	1.2	2.51	1.57
Avg	92.8	90.3	2.03	1.94	Avg	0.6	0.8	2.43	1.85
Std dev	3.0	2.2	0.02	0.01	Std dev	0.4	0.6	0.08	0.44

TABLE 24

Summary

effect of water immersion on closed cell and foam density

Item no	Sample 1676-	% Closed cell		Density, pcf	
		Before	After	Before	After
4	48-11	98.6	97.0	2.20	2.20
5	48-12	92.8	90.3	2.03	1.94
9	48-9	88.8	87.9	2.22	2.16
11	46-10	95.2	90.7	2.11	2.12
14	48-7	92.1	95.8	2.02	2.02
15	48-6	94.0	91.4	2.40	2.36
17	48-1	91.2	93.5	2.20	2.25
18	48-8	94.8	97.0	2.22	2.20
19	46-5	89.2	91.7	2.04	2.02
21	46-13	92.3	90.2	2.37	2.31
22	46-8	89.5	92.9	2.16	2.21
23	46-7	93.0	92.8	2.13	2.11
24	50-2	23.2	No Sample	26.8	No Sample
25	50-3	9.4	12.1	13.6	14.8
26	50-5	0.6	0.8	2.43	1.85

TABLE 25

Effect of water immersion on compressive properties

Sample 1676-	10% Compressive Before	10% Compressive After	Modulus, psi Before	Modulus, psi After	Sample 1676-	10% Compressive Before	10% Compressive After	Modulus, psi Before	Modulus, psi After	Sample 1676-	10% Compressive Before	10% Compressive After	Modulus, psi Before	Modulus, psi After
46 - 5	29.0	28.2	787	567	46 - 10	20.4	18.5	477	425	48 - 6	28.5	32.0	410	817
Item 19	28.0	28.5	756	561	Item 11	19.8	17.7	396	449	Item 15	30.8	32.1	538	855
	27.8	29.8	564	794		21.8	19.0	622	414		32.4	30.5	635	980
	27.3	29.1	562	671		23.1	20.2	513	433		33.0	31.6	750	956
	27.9	28.4	561	807		19.3	19.3	442	483		29.8	31.9	726	733
Avg	28.0	28.8	646	680	Avg	20.9	18.9	490	441	Avg	30.9	31.6	612	868
Std dev	0.6	0.7	115	118	Std dev	1.6	0.9	86	27	Std dev	1.8	0.7	140	102
46 - 7	24.0	23.4	367	398	46 - 13	28.4	26.9	656	542	48 - 7	23.0	23.2	600	602
Item 23	23.0	22.3	581	392	Item 21	27.6	27.0	643	435	Item 14	22.3	22.5	379	523
	22.6	23.9	333	370		27.1	24.7	550	716		22.3	21.7	332	419
	-	22.7	245	551		28.0	23.5	579	589		23.8	22.2	625	548
	22.0	22.5	541	320		27.1	25.0	523	372		24.1	21.6	648	394
Avg	22.9	23.0	413	406	Avg	27.6	25.4	590	531	Avg	23.1	22.2	517	497
Std dev	0.8	0.7	143	87	Std dev	0.6	1.5	58	134	Std dev	0.8	0.7	149	88
46 - 8	25.9	28.8	786	798	48 - 1	23.7	17.4	643	422	48 - 8	28.1	26.0	487	500
Item 22	24.5	26.8	830	637	Item 17	22.0	17.4	686	251	Item 18	28.5	25.0	659	510
	27.0	26.7	441	677		22.5	-	645	-		30.7	24.5	710	451
	26.1	26.1	542	687		21.4	20.4	662	555		30.5	25.5	663	519
	28.0	27.2	804	722		23.1	19.0	775	313		28.5	26.7	639	532
Avg	26.3	27.1	681	704	Avg	22.5	18.6	682	385	Avg	29.3	25.5	632	502
Std dev	1.3	1.0	177	61	Std dev	0.9	1.4	55	133	Std dev	1.2	0.9	85	31

TABLE 25 (cont)

Effect of water immersion on compressive properties

Sample 1676-	10% Compressive Before	10% Compressive After	Modulus, psi Before	Modulus, psi After	Sample 1676-	10% Compressive Before	10% Compressive After	Modulus, psi Before	Modulus, psi After
48 - 9	30.9	31.3	624	651	50 - 2*	1.7	No	10.0	No
Item 9	29.6	29.5	468	671	Item 24	1.7	Sample	8.4	Sample
	29.4	29.5	547	603		1.4	"	10.8	"
	33.4	30.7	733	583		1.6	"	10.1	"
	33.2	30.9	837	709		1.8	"	10.4	"
Avg	31.3	30.4	642	643	Avg	1.6	"	9.9	"
Std dev	1.9	0.8	147	51	Std dev	0.2	"	0.9	"
48 - 11	43.6	40.7	928	1048	50 - 3**	2.8	2.5	36.8	31.9
Item 4	43.0	38.0	962	625	Item 25	1.9	1.9	41.6	25.2
	39.9	39.0	725	658		2.7	2.2	70.9	33.1
	40.5	31.3	881	451		2.1	2.7	50.8	32.7
	40.8	38.0	909	816		1.8	2.2	40.5	29.9
Avg	41.6	37.4	881	720	Avg	2.3	2.3	48.1	30.6
Std dev	1.6	3.6	92	225	Std dev	0.5	0.3	13.7	3.2
48 - 12	21.6	22.6	608	624	50 - 5	6.3	12.3	178	643
Item 5	21.1	23.6	720	639	Item 26	8.7	5.8	196	196
	20.4	22.6	575	414		5.4	8.0	118	296
	22.3	23.6	498	647		6.5	11.2	215	464
	25.4	22.5	571	381		6.0	7.0	202	234
Avg	22.2	23.0	594	541	Avg	6.6	8.9	182	367
Std dev	1.9	0.6	81	132	Std dev	1.2	2.8	38	185

* Compressive at 30% deflection; flexible foam.
** Compressive at 20% deflection; flexible foam.

TABLE 26

Summary

effect of water immersion on compressive properties, psi

Item no	Sample 1676-	10% Compressive		Modulus	
		Before	After	Before	After
4	48-11	41.6	37.4	881	720
5	48-12	22.2	23.0	594	541
9	48-9	31.3	30.4	644	643
11	46-10	20.9	18.9	490	441
14	48-7	23.1	22.2	517	497
15	48-6	30.9	31.6	612	868
17	48-1	22.5	18.6	682	385
18	48-8	29.3	25.5	632	502
19	46-5	28.0	28.8	646	680
21	46-13	27.6	25.4	590	531
22	46-8	26.3	27.1	681	704
23	46-7	22.9	23.0	413	406
24*	50-2	1.6	No Sample	9.9	No Sample
25**	50-3	2.3	2.3	48.1	30.6
26	50-5	6.6	8.9	182	367

*Flexible Foam - compressive at 30% deflection
**Flexible Foam - compressive at 20% deflection

TABLE 27

Summary - effect of 96 hours water immersion on foam properties

Item no	Sample 1676-	Radiant panel, Is E162 Before	Radiant panel, Is E162 After	Radiant panel, Is E162 - CCC-2 Before	Radiant panel, Is E162 - CCC-2 After	Radiant panel, smoke area E162 Before	Radiant panel, smoke area E162 After	Radiant panel, smoke area E162 - CCC-2 Before	Radiant panel, smoke area E162 - CCC-2 After	% Closed cell Before	% Closed cell After	10% Compressive strength, psi Before	10% Compressive strength, psi After	Foam area increase %	Weight increase, g 15-30 min	Weight increase, g 48 hr
4	48-11	144	152	1367	1815	2814	2448	6300	7003	99	97	42	37	-0.5	34	0.0
5	48-12	2	3	39	61	1100	1490	2468	3590	93	90	22	23	0.2	28	-0.2
9	48-9	112	176	645	819	1806	2358	3118	3470	89	88	31	30	-0.0	47	-0.8
11	46-10	68	111	781	1628	2329	3250	4581	4867	95	91	21	19	-2.4	30	-0.2
14	48-7	10	15	696	1563	1449	1790	3210	4383	92	96	23	22	0.6	29	-0.1
15	48-6	12	10	1245	1493	1595	2133	3738	5560	94	91	31	32	0.6	29	0.0
17	48-1	65	56	1551	1862	1770	1750	5280	4560	91	94	23	19	0.1	21	-0.2
18	48-8	66	89	2845	4177	1912	1848	4587	5017	95	97	29	26	-0.1	43	-0.1
19	46-5	41	53	3185	2097	1816	2383	4233	4995	89	92	28	29	0.5	42	-0.2
21	46-13	83	46	2165	2737	1860	2367	3335	4635	92	90	28	25	-0.3	38	0.1
22	46-8	176	245	981	2312	2218	3065	5600	6775	90	93	26	27	0.2	25	0.0
23	46-7	13	33	1748	1612	1533	2340	3253	5490	93	93	23	23	0.4	34	0.1
24	50-2	75	85	529	103	7427	9773	8025	5833	23	ND	2	ND	ND	84	-1.5
25	50-3	16	5	1	9	3138	4795	8400	6598	9	12	2	2	ND	840	-37
26	50-5	3	5	3	2	0	2975	4970+	4090	1	1	7	9	-0.9	629	-8 (1 mo)
27	50-4	97	54	1219	1875	3560	3625	5243	7845	ND	ND	ND	ND	-0.3	34	-0.5

Note: ND = No data

Dry Aging Tests

Dry-aging tests were conducted to determine if the flame retardants for the candidates were volatile or fugitive. The dry-aging was conducted by storing nine, 6 inch by 18 inch by 1 inch thick samples of each candidate foam in an air circulating oven for 28 days at 100°C. After aging, the samples were removed, allowed to equilibrate at room temperature, weighed and subjected to comparison testing.

Flame spread by the two radiant panel tests and flame penetration tests were used for the comparison. Significant changes in either test values could be considered cause for rejection.

ASTM E162 Tests - Four specimens of the dry aged foam samples were subjected to the ASTM E162 radiant panel test. The results are shown in Table 28 along with the average and standard deviation. The data are summarized and compared with virgin foam in Table 29.

The data show that dry aging did not have much effect on most of the foams. The flame spread properties of Items 18, 22 and 27 deteriorated slightly, and the smoke areas of Items 9, 22, 24 and 26 increased moderately. None of the changes were felt to be significant.

E162-CCC-2 Tests - Four of the dry-aged foam samples were also subjected to the modified radiant panel test. The results are shown in Table 30 along with the average and standard deviation. These data are summarized and compared with the virgin foam samples in Table 31.

The flame spread index of Item 22 increased greatly, and that of Item 24 actually decreased as did the smoke area. The reason for this improvement in properties for the latter candidate is not known. Item 21 was the only foam showing an increase in smoke area. In general, however, the effect of dry aging upon the flame spread properties was negligible.

Changes in Weight - The effect of 28 days dry aging at 100°C on the sample weight is shown in Table 32 along with the average and standard deviation. These data are summarized in Table 33.

The weight loss was relatively low for all but Items 24, 25 and 26, for which the weight loss was excessive. It is likely that 100°C was close to the thermal decomposition temperature of the Hypol-based foam (Item 25), which is basically a flexible foam loaded with mostly inorganics. The reason(s) for the high weight loss for Items 24 and 26 is not at all clear, but since the loss in weight at these elevated temperatures was not accompanied by a significant loss of flame retardancy, the weight loss is probably of no consequence.

Flame Penetration - In the event of a fire near a stopping, it is highly desirable that the stopping maintain its seal as long as possible. In order to maintain the seal, the foam must not only resist ignition and

TABLE 28

ASTM E162 Radiant panel data after dry aging

Sample 1676-	Q	F	Is	In burned	Smoke Peak	Smoke Area	Sample 1676-	Q	F	Is	In burned	Smoke Peak	Smoke Area
46 - 5	8.4	14.8	124	6	11	1940	48 - 8	6.8	104.3	709	10	21	2850
Item 19	7.0	12.4	87	7	14	2450	Item 18	4.7	102.8	483	9	13	2720
	4.5	13.8	63	7	10	1560		8.1	7.0	57	8	10	2430
	5.4	23.5	126	9	20	2520		6.0	6.4	39	8	7	1590
Avg	6.3	16.1	100	7.3	13.8	2118	Avg	6.4	55.1	322	8.8	12.8	2398
Std dev	1.7	5.0	31	1.3	4.5	453	Std dev	1.4	55.9	330	1.0	6.0	566
46 - 7	2.8	2.4	7	3	18	(5280)	48 - 9	2.1	60.2	127	17	25	2780
Item 23	3.9	2.5	10	3	13	1710	Item 9	2.3	63.8	145	17	27	3490
	2.8	2.5	7	3	12	2220		4.1	58.3	236	17	21	1820
	3.2	2.7	9	4	11	1850		4.1	61.0	247	17	23	2820
Avg	3.2	2.5	8	3.3	13.5	1927	Avg	3.1	60.8	189	17.0	24.0	2728
Std dev	0.5	0.1	2	0.5	3.1	264	Std dev	1.1	2.3	62	0	2.6	687
46 - 8	7.3	88.5	645	11	40	ND	48 - 11	4.9	50.1	243	12	25	2770
Item 22	7.3	48.5	354	12	40	3770	Item 4	4.1	32.6	132	11	28	2610
	6.0	38.8	232	12	36	3120		4.1	38.7	157	10	20	2680
	9.2	28.5	263	10	36	2820		5.4	28.7	153	11	27	3600
Avg	7.5	51.1	374	11.3	38.0	3237	Avg	4.6	37.5	171	11.0	25.0	2915
Std dev	1.3	26.3	188	1.0	2.3	486	Std dev	0.6	9.3	49	0.8	3.6	461
46 - 10	8.1	11.6	94	8	17	2270	48 - 12	2.9	1.0	3	<3	14	1750
Item 11	8.9	102.5	(913)	8	19	2670	Item 5	1.6	1.0	2	<3	10	(980+)
	6.5	22.8	148	8	21	2920		2.9	1.0	3	<3	9	890
	6.8	9.2	62	8	17	2360		2.1	1.0	2	<3	10	1080
Avg	7.6	36.5	101	8	18.5	2555	Avg	2.4	1.0	2	<3	10.8	1240
Std dev	1.1	44.4	43	0	1.9	298	Std dev	0.6	0.0	1	0	2.2	452

TABLE 28 (cont)

ASTM E162 Radiant panel data after dry aging

Sample 1676-	Q	F	Is	In burned	Smoke Peak	Smoke Area	Sample 1676-	Q	F	Is	In burned	Smoke Peak	Smoke Area
46 - 13	7.3	9.0	66	7	8	1520	50 - 2	9.7	10.0	96	14	6	8920
Item 21	7.3	5.5	40	7	10	2020	Item 24	10.0	10.1	101	14	7	10,920
	8.3	9.6	79	7	8	(900+)		9.3	10.9	100	14	7	9990
	5.4	19.6	105	9	20	2320		11.7	9.7	113	14	9	14,430
Avg	7.0	10.9	73	7.5	11.5	1953	Avg	10.2	10.1	103	14.0	7.3	11,065
Std dev	1.2	6.0	27	1.0	5.7	404	Std dev	1.1	0.5	7	0	1.3	2388
48 - 1	6.7	6.3	42	7	9	790	50 - 3	4.9	1.0	5	<3	3	3090
Item 17	6.5	5.7	37	7	9	1470	Item 25	5.4	1.0	5	<3	4	5170
	5.2	22.3	116	7	9	1230		5.4	1.0	5	<3	3	3240
	5.7	7.7	43	7	8	1380		3.7	1.0	4	<3	2	1730
Avg	6.0	10.5	59	7.0	8.8	1218	Avg	4.8	1.0	5	<3	3.0	3308
Std dev	0.7	7.9	38	0.0	0.5	302	Std dev	0.8	0	1	-	0.8	1415
48 - 6	3.2	1.9	6	5	10	1500	50 - 4	9.7	32.5	316	9	23	2250
Item 15	5.7	1.7	9	3	11	2060	Item 27	8.1	10.5	85	8	24	3430
	6.2	2.3	14	3	10	1420		8.3	52.4	433	8	31	4260
	4.9	2.2	11	4	11	1300		8.4	55.6	468	8	32	2910
Avg	5.0	2.0	10	3.8	10.5	1570	Avg	8.6	37.8	326	8.3	27.5	3213
Std dev	1.3	0.3	3	1.0	0.6	337	Std dev	0.7	20.9	173	0.5	4.7	849
48 - 7	3.2	2.1	7	3	12	1990	50 - 5	2.8	1.0	3	0	1.8	1230+
Item 14	4.9	2.7	13	5	18	(900+)	Item 26						
	7.3	3.0	22	5	11	(800+)							
	5.2	2.3	12	5	10	1870							
Avg	5.1	2.5	14	4.5	12.8	1930	Avg	2.8	1.0	3	0	1.8	1230+
Std dev	1.7	0.4	6	1.0	3.6	85	Std dev	NM	NM	NM	NM	NM	NM

Note: ND = No data
NM = Not meaningful

TABLE 29

ASTM E162 Radiant panel - summary of effect of dry aging

Item no	Sample 1676-	Q		F		Is		In burned		Peak smoke		Smoke area	
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
4	48-11	4.8	4.6	30.3	37.5	144	171	11.4	11.0	24.6	25.0	2814	2915
5	48-12	2.4	2.4	1.0	1.0	2	2	1.0	<3	11.0	10.8	1100	1240
9	48-9	1.9	3.1	59.7	60.8	112	189	11.3	17.0	22.1	24.0	1806	2728
11	46-10	3.5	7.6	19.8	36.5	68	101	6.5	8.0	18.8	18.5	2329	2555
14	48-7	4.2	5.1	2.5	2.5	10	14	3.5	4.5	11.5	12.8	1449	1930
15	48-6	5.7	5.0	2.2	2.0	12	10	3.0	3.8	16.1	10.5	1595	1570
17	48-1	5.1	6.0	12.4	10.5	65	59	4.0	7.0	13.0	8.8	1770	1218
18	48-8	7.3	6.4	9.4	55.1	66	322	4.5	8.8	11.5	12.8	1912	2398
19	46-5	5.6	6.3	7.4	16.1	41	100	3.0	7.3	13.9	13.8	1816	2118
21	46-13	5.5	7.0	15.4	10.9	83	73	5.5	7.5	13.1	11.5	1860	1953
22	46-8	5.7	7.5	35.5	51.1	176	374	10.0	11.3	27.3	38.0	2218	3237
23	46-7	4.9	3.2	2.7	2.5	13	8	3.0	3.3	12.0	13.5	1533	1927
24	50-2	8.4	10.2	8.9	10.1	75	103	14.0	14.0	7.3	7.3	7427	11,065
25	50-3	6.6	4.8	2.4	1.0	16	5	3.0	<3	3.0	3.0	3138	3308
26	50-5	2.4	2.8	1.0	1.0	3	3	<3	0	0	1.8	0	1230+
27	50-4	6.9	8.6	14.0	37.8	97	326	9.3	8.3	32.0	27.5	3560	3213

TABLE 30

E162-CCC-2 Modified radiant panel data after dry aging

Sample 1676-	Q	F	Is	In burned	Smoke Peak	Smoke Area	Sample 1676-	Q	F	Is	In burned	Smoke Peak	Smoke Area
46 - 5	9.9	251	2485	18	50	3930	46 - 13	8.5	234	1985	18	52	4370
Item 19	8.3	251	2083	18	48	3800	Item 21	7.3	251	1832	18	47	4840
	8.0	251	2008	18	47	4010		10.2	251	2565	18	51	6000
	8.5	234	1992	18	48	3430		9.9	251	2492	18	50	5290
Avg	8.7	247	2142	18	48.3	3793	Avg	9.0	247	2219	18	50.0	5125
Std dev	0.8	9	232	0	1.3	257	Std dev	1.4	9	365	0	2.2	694
46 - 7	4.5	193	867	18	45	3860	48 - 1	10.4	251	2603	18	56	5190
Item 23	4.6	193	886	18	48	3120	Item 17	11.0	201	2201	18	56	5360
	5.2	193	1002	18	40	3100		11.0	251	2748	18	63	4770
	5.4	193	1040	18	43	3130		7.7	251	1943	18	56	4390
Avg	4.9	193	949	18	44.0	3303	Avg	10.0	239	2374	18	57.8	4928
Std dev	0.4	0	85	0	3.4	372	Std dev	1.5	25	369	0	3.5	436
46 - 8	15.3	218	3337	18	60	4990	48 - 6	5.8	168	979	18	32	3850
Item 22	14.6	218	3178	18	64	4940	Item 15	5.8	168	979	18	29	3330
	13.3	218	2895	18	62	3900		6.6	168	1101	18	34	3555
	13.1	218	2851	18	61	5470		6.3	168	1053	18	34	3615
Avg	14.1	218	3065	18	61.8	4825	Avg	6.1	168	1028	18	32.3	3588
Std dev	1.1	0	232	0	1.7	661	Std dev	0.4	0	60	0	2.4	214
46 -10	6.6	150	987	15	49	3860	48 - 7	6.6	188	1233	18	50	ND
Item 11	6.3	150	943	15	52	4040	Item 14	6.1	188	1150	18	41	3550
	7.6	150	1140	15	50	3720		7.0	188	1314	18	42	4530
	10.5	150	1578	15	50	3920		6.1	188	1150	18	ND	3860
Avg	7.8	150	1162	15	50.3	3885	Avg	6.5	188	1212	18	44.3	3980
Std dev	1.9	0	290	0	1.3	133	Std dev	0.4	0	79	0	4.9	501

TABLE 30 (cont)

E162-CCC-2 Modified radiant panel data after dry aging

Sample 1676-	Q	F	Is	In burned	Smoke Peak	Smoke Area	Sample 1676-	Q	F	Is	In burned	Smoke Peak	Smoke Area
48 - 8	8.0	218	1748	18	48	3070	50 - 2	7.2	13	92	12	7	2440
Item 18	11.4	218	2479	18	53	6560	Item 24	8.9	13	114	12	11	4000
	13.1	251	3298	18	53	3750		7.7	13	103	12	7	2250
	11.4	168	1898	18	49	3370		6.1	13	78	12	12	1810
Avg	11.0	214	2356	18	50.8	4188	Avg	7.5	13	97	12	9.3	2625
Std dev	2.1	34	703	0	2.6	1606	Std dev	1.2	0.3	15	0	2.6	954
48 - 9	6.0	168	1004	18	23	3670	50 - 3	5.7	4	25	3	-	2060
Item 9	8.0	134	1079	18	26	(2570+)	Item 25	0.9	4	4	3	9	7020
	6.0	176	1054	18	23	3080		0.3	4	1	3	7	5580
	8.0	134	1079	18	23	2870		0.2	4	1	3	9	9970
Avg	7.0	153	1054	18	23.8	3207	Avg	1.8	4	8	3	8.3	6158
Std dev	1.2	22	35	0	1.5	415	Std dev	2.6	0	11	0	1.2	3286
48 - 11	8.0	176	1413	18	24	4390	50 - 4	14.6	129	1888	18	73	4520
Item 4	8.0	176	1413	18	30	5500	Item 27	10.2	126	1288	18	48	3420
	8.0	176	1413	18	27	5460		13.9	134	1863	18	77	4820
	7.9	176	1387	18	ND	6290		10.1	133	1336	18	62	5030
Avg	8.0	176	1407	18	27.0	5410	Avg	12.2	131	1594	18	65.8	4448
Std dev	0.1	0	13	0	3.0	780	Std dev	2.4	4	326	0	13.7	716
48 - 12	0.6	1	0.6	<3	29	2500	50 - 5	8.0	1.0	8	<3	3.0	5430
Item 5	0.4	1	0.6	<3	32	2100	Item 26						
	0.4	1	0.4	<3	30	2140							
	0.6	1	0.6	<3	31	2440							
Avg	0.5	1	0.5	<3	30.5	2295	Avg	8.0	1.0	8	<3	3.0	5430
Std dev	0.1	0	0.1	0	1.3	204	Std dev	NM	NM	NM	NM	NM	NM

Note: ND = No data
NM = Not meaningful

TABLE 31

E162-CCC-2 Modified radiant panel - Summary of effect of dry aging

Item no	Sample 1676-	Q		F		Is		In burned		Peak smoke		Smoke area	
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
4	48-11	8.0	8.0	171	176	1367	1407	18	18	68.4	27.0	6300	5410
5	48-12	0.4	0.5	101	1	39	1	3	<3	32.1	30.5	2468	2295
9	48-9	4.0	7.0	163	153	645	1054	18	18	34.8	23.8	3118	3207
11	46-10	4.6	7.8	170	150	781	1162	18	15	53.5	50.3	4581	3885
14	48-7	4.5	6.5	156	188	696	1212	18	18	43.1	44.3	3210	3980
15	48-6	5.7	6.1	218	168	1245	1028	18	18	37.9	32.3	3738	3588
17	48-1	8.0	10.0	193	239	1551	2374	18	18	60.9	57.8	5280	4928
18	48-8	9.5	11.0	301	214	2845	2356	18	18	67.5	50.8	4587	4188
19	46-5	9.1	8.7	351	247	3185	2142	18	18	53.8	48.3	4233	3793
21	46-13	6.2	9.0	351	247	2165	2219	18	18	56.5	50.0	3335	5125
22	46-8	9.7	14.1	101	218	981	3065	18	18	75.6	61.8	5600	4825
23	46-7	5.8	4.9	301	193	1748	949	18	18	43.8	44.0	3253	3303
24	50-2	40.2	7.5	13	13	529	97	12	12	6.6	9.3	8025	2625
25	50-3	0.7	1.8	1	4	1	8	1	3	5.5	8.3	8400	6158
26	50-5	2.8	8.0	1	1	3	8	<3	<3	2	3.0	4970+	5430
27	50-4	10.0	12.2	120	131	1219	1594	15	18	71.8	65.8	5243	4448

flame spread, but it must also resist flame penetration. There is no direct correlation between flame spread and flame penetration.

Flame penetration testing was conducted according to procedures developed by the Bureau.[2] Four sample specimens, 6 inches square and 1 inch thick, (from foam 3 to 7 days old) were cut parallel to the rise without the dense foam skin. Weight and size measurements were accurately determined for density calculations.

The test apparatus (Figure 5) consists of the sample holder and flame burner equipment. The equipment is placed in a hood maintained at 75° ± 2°F. The fuel source is propane gas. The mirror at the base of the apparatus is used to observe the flame penetration through the sample being tested.

The procedure is as follows:

> The pencil-flame burner head is placed vertically above the axis of the hole in the Transite and adjusted to be 2.0 ± 0.25 inches from the face of a foam specimen when inserted in place. Before the specimen is inserted, the burner is lit and adjusted to produce a steady test flame with a 1.5 inch-long center blue cone. The test flame temperature measured by a thermocouple 2.0 ± 0.25 inches below the burner head was 2,150° ± 25°F for a period of not less than 5 minutes, without a foam specimen in place.
>
> The foam specimen is positioned as quickly as possible on the sample holder, and a timer started. The test continues until flame penetration is observed, or 1000 seconds, at which time the specimen is removed and the flame temperature measured again as described above.

Flame penetration tests were run on both virgin and dry-aged foam samples. These data are shown in Table 34 along with the averages and standard deviation. A summary of the data is shown in Table 35.

Items 18 and 26 have low flame penetration times. Item 26 is highly fire resistant, but upon application of a flame, the foam erodes and shrinks to form a "star" crack or hole. This behavior is typical of many isocyanurate foams. Item 9, 11 and 14 also showed low flame penetration times but it was discovered that the temperature was much higher than standard. Upon retesting the foams at 2150°F, they were found to have good flame penetration times. Unfortunately, we could not retest the dry aged samples, but we would expect them to be satisfactory based upon the mode of failure.

[2]Mitchell, D. W., Murphy, E. M. and Nagy, J. Fire Hazard of Urethane Foam in Mines. BuMines RI 6837, 1968, pp 5-7.
Mitchell, D. W., Nagy and Murphy, E. M. Rigid Foam for Mines. BuMines RI 6366, 1964, pp 16-8.

TABLE 32

Effect of dry aging on weight

Sample 1676-	Weight Before	Weight After	Weight loss g	Weight loss %	Sample 1676-	Weight Before	Weight After	Weight loss g	Weight loss %	Sample 1676-	Weight Before	Weight After	Weight loss g	Weight loss %
46 - 5	56.2	54.4	1.8	3.2	46 - 10	54.5	52.2	2.3	4.2	48 - 6	62.0	60.7	1.3	2.1
Item 19	59.7	58.3	1.4	2.3	Item 11	53.4	51.0	2.4	4.5	Item 15	61.3	59.8	1.5	2.4
	60.3	58.7	1.6	2.7		48.4	46.0	2.4	5.0		62.2	61.1	1.1	1.8
	56.0	54.4	1.6	2.9		53.3	50.9	2.4	4.5		62.0	60.9	1.1	1.8
	60.0	58.5	1.5	2.5		51.3	48.9	2.4	4.7		63.0	61.8	1.2	1.9
	60.0	58.7	1.3	2.2		52.0	49.6	2.4	4.6		59.1	58.0	1.1	1.9
	57.3	55.7	1.6	2.8		46.5	44.1	2.4	5.2		54.7	52.8	1.9	3.5
	55.2	54.0	1.2	2.2		56.6	54.3	2.3	4.1		62.3	60.6	1.7	2.7
Avg	NM	NM	1.5	2.6	Avg	NM	NM	2.4	4.6	Avg	NM	NM	1.4	2.3
Std dev	NM	NM	0.2	0.4	Std dev	NM	NM	0.0	0.4	Std dev	NM	NM	0.3	0.6
46 - 7	52.8	51.5	1.3	2.5	46 - 13	57.0	56.0	1.0	1.8	48 - 7	60.6	59.5	1.1	1.8
Item 23	51.7	50.1	1.6	3.1	Item 21	59.5	58.8	0.7	1.2	Item 14	61.1	60.0	1.1	1.8
	52.7	51.2	1.5	2.8		57.0	56.2	0.8	1.4		58.7	57.4	1.3	2.2
	49.0	48.0	1.0	2.0		56.0	55.0	1.0	1.8		58.5	57.5	1.0	1.7
	53.0	52.9	0.1	0.2		55.6	54.7	0.9	1.6		58.2	56.9	1.3	2.2
	50.7	50.0	0.7	1.4		57.9	57.0	0.9	1.6		58.7	57.6	1.1	1.9
	52.0	50.6	1.4	2.7		55.6	54.9	0.7	1.3		55.5	54.3	1.2	2.2
	53.8	52.8	1.0	1.9		55.4	54.5	0.9	1.6		61.0	60.3	0.7	1.1
Avg	NM	NM	1.1	2.1	Avg	NM	NM	0.9	1.5	Avg	NM	NM	1.1	1.9
Std dev	NM	NM	0.5	0.9	Std dev	NM	NM	0.1	0.2	Std dev	NM	NM	0.2	0.4
46 - 8	51.8	49.6	2.2	4.2	48 - 1	58.8	57.6	1.2	2.0	48 - 8	52.3	51.7	0.6	1.1
Item 22	53.4	50.9	2.5	4.7	Item 17	59.0	58.1	0.9	1.5	Item 18	53.8	53.2	0.6	1.1
	53.3	50.3	3.0	5.6		60.0	59.1	0.9	1.5		59.9	59.7	0.2	0.3
	53.5	50.0	3.5	6.5		55.2	54.3	0.9	1.6		62.8	62.6	0.2	0.3
	54.9	52.0	2.9	5.3		53.5	52.5	1.0	1.9		63.8	63.6	0.2	0.3
	51.3	48.0	3.3	6.4		53.3	52.3	1.0	1.9		62.6	62.2	0.4	0.6
	54.9	51.5	3.4	6.2		49.9	48.6	1.3	2.6		64.8	64.3	0.5	0.8
	53.8	50.7	3.1	5.8		64.9	64.0	0.9	1.4		60.0	59.3	0.7	1.2
Avg	NM	NM	3.0	5.6	Avg	NM	NM	1.0	1.8	Avg	NM	NM	0.4	0.7
Std dev	NM	NM	0.4	0.8	Std dev	NM	NM	0.2	0.4	Std dev	NM	NM	0.2	0.4

TABLE 32 (cont)

Effect of dry aging on weight

Sample 1676-	Weight Before	Weight After	Weight loss g	Weight loss %
48 - 9 Item 9	58.0	54.0	4.0	6.9
	54.7	51.0	3.7	6.8
	58.6	55.3	3.3	5.6
	62.2	59.5	2.7	4.3
	55.4	51.8	3.6	6.5
	60.0	56.3	3.7	6.2
	59.4	56.1	3.3	5.6
	58.7	55.1	3.6	6.1
Avg	NM	NM	3.5	6.0
Std dev	NM	NM	0.4	0.8
48 - 11 Item 4	58.6	58.9	-0.3	-0.5
	55.9	56.0	-0.1	-0.2
	58.5	58.7	-0.2	-0.3
	55.5	55.8	-0.3	-0.5
	56.0	55.9	0.1	0.2
	60.2	60.6	-0.4	-0.7
	56.2	56.9	-0.7	-1.2
	53.0	53.0	0.0	0.0
Avg	NM	NM	-0.2	-0.4
Std dev	NM	NM	0.3	0.4
48 - 12 Item 5	51.4	48.8	2.6	5.1
	54.2	51.6	2.6	4.8
	50.6	47.9	2.7	5.3
	50.5	47.9	2.6	5.1
	52.6	50.2	2.4	4.6
	46.2	43.9	2.3	5.0
	47.1	44.9	2.2	4.7
	51.8	49.2	2.6	5.0
Avg	NM	NM	2.5	4.9
Std dev	NM	NM	0.2	0.3

Sample 1676-	Weight Before	Weight After	Weight loss g	Weight loss %
50 - 2 Item 24	780	762	18	NM*
	768	750	18	NM
	802	783	19	NM
	733	713	20	NM
	761	744	17	NM
	804	786	18	NM
	783	764	19	NM
	759	741	18	NM
Avg	NM	NM	18.4	NM*
Std dev	NM	NM	0.9	
50 - 3 Item 25	831	812	19	NM*
	834	814	20	NM
	854	833	21	NM
	836	817	19	NM
	888	868	20	NM
	920	898	22	NM
	856	835	21	NM
	860	840	20	NM
Avg	NM	NM	20.3	NM*
Std dev	NM	NM	1.0	NM
50 - 4 Item 27	60.0	57.8	2.2	3.7
	60.4	58.3	2.1	3.5
	59.1	56.7	2.4	4.1
	53.5	51.2	2.3	4.3
	55.3	53.1	2.2	4.0
	56.6	54.1	2.5	4.4
	59.4	56.8	2.6	4.4
	52.6	48.8	3.8	7.2
Avg	NM	NM	2.5	4.4
Std dev	NM	NM	0.5	1.2

Sample 1676-	Weight Before	Weight After	Weight loss g	Weight loss %
50 - 5 Item 26	87.6	71.5	16.1	18.4
	75.3	62.4	12.9	17.1
	37.1	32.1	5.0	13.5
Avg	NM	NM	11.3	16.3
Std dev	NM	NM	5.7	2.5

*Not meaningful

TABLE 33

Summary of effect of dry aging on weight

Item no	Sample 1676-	Weight loss g	Weight loss %
4	48-11	-0.2	-0.4
5	48-12	2.5	4.9
9	48-9	3.5	6.0
11	46-10	2.4	4.6
14	48-7	1.1	1.9
15	48-6	1.4	2.3
17	48-1	1.0	1.8
18	48-8	0.4	0.7
19	46-5	1.5	2.6
21	46-13	0.9	1.5
22	46-8	3.0	5.6
23	46-7	1.1	2.1
24	50-2	18.4	NM*
25	50-3	20.3	NM*
26	50-5	11.3	16.3
27	50-4	2.5	4.4

*Not meaningful

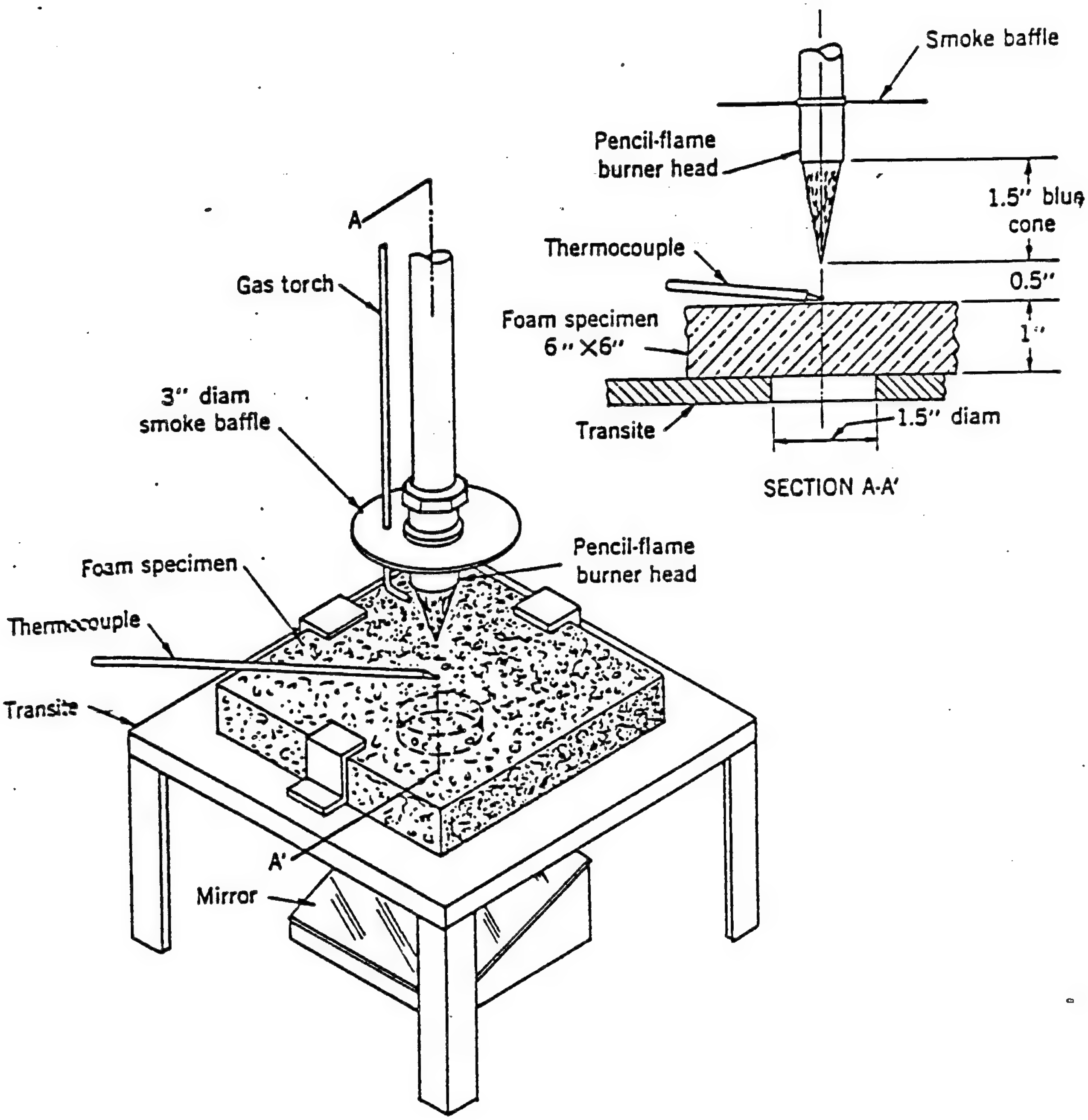


FIGURE 5 - General arrangement of flame-endurance test

TABLE 34

Effect of dry aging on flame penetration

Sample 1676-	Penetration time, sec Before	After	Sample 1676-	Penetration time, sec Before	After	Sample 1676-	Penetration time, sec Before	After	Sample 1676-	Penetration time, sec Before	After
46 - 5	1000+	868	46 - 13	667	1000	48 - 8	253	179	50 - 2	1000+	640
Item 19	1000+	1000+	Item 21	1000+	870	Item 18	176	215	Item 24	1000+	531
	1000+	1000+		716	794		176	192		931	678
	1000+	1000+		1000	875		129	203		724	500
Avg	1000+	967+	Avg	846+	885	Avg	184	197	Avg	914+	587
Std dev	NM	NM	Std dev	179+	85	Std dev	51	15	Std dev	131	85
46 - 7	1000+	1000+	48 - 1	944	885	48 - 9	8(624)	6	50 - 3	1000+	1000+
Item 23	1000+	1000+	Item 17	862	1000+	Item 9	9(1000+)	7	Item 25	1000+	1000+
	1000+	1000+		1000	1000+		9(1000+)	6		1000+	1000+
	1000+	1000+		226	334		8(ND)	9		1000+	1000+
Avg	1000+	1000+	Avg	758	805+	Avg	9(875+)	7	Avg	1000+	1000+
Std dev	NM	NM	Std dev	359	318+	Std dev	1(217+)	1	Std dev	NM	NM
46 - 8	568	354	48 - 6	1000+	1000+	48 - 11	991	725	50 - 4	1000+	1000+
Item 22	258	867	Item 15	1000+	1000+	Item 4	1000+	1000+	Item 27	1000+	1000+
	281	1000		1000+	1000+		1000+	1000+		1000+	1000+
	750	150		1000+	1000+		1000+	810		1000+	1000+
Avg	464	593	Avg	1000+	1000+	Avg	998+	884+	Avg	1000+	1000+
Std dev	237	406	Std dev	NM	NM	Std dev	5+	139+	Std dev	NM	NM
46 - 10	8(205)	7	48 - 7	297(1000+)	293	48 - 12	1000+	970	50 - 5	82	73
Item 11	12(851)	6	Item 14	340(1000+)	1000	Item 5	1000+	1000+	Item 26	150	153
	7(1000+)	6		82(1000+)	636		1000+	794			
	7(915)	6		91(1000+)	1000		1000+	1000+			
Avg	9(743+)	6?	Avg	203(1000+)	732	Avg	1000+	941+	Avg	116	113
Std dev	2(364+)	1	Std dev	135(NM)	339	Std dev	NM5+	99+	Std dev	48	57

Note: Figures inside ( ) indicate retest data.
NM = Not meaningful
ND = No data

TABLE 35

Summary of effect of dry aging on flame penetration

Item no	Sample 1676-	Flame penetration time, sec Before	After
4	48-11	998+	884+
5	48-12	1000+	941+
9	48-9	9* (875+)	7*
11	46-10	9* (743+)	6*
14	48-7	203* (1000+)	732
15	48-6	1000+	1000+
17	48-1	758	805+
18	48-8	184	197
19	46-5	1000+	967+
21	46-13	846+	885
22	46-8	464	593
23	46-7	1000+	1000+
24	50-2	914+	587
25	50-3	1000+	1000+
26	50-5	116	113
27	50-4	1000+	1000+

*Flame temperatures were believed to be high during these tests. Figures inside ( ) indicate retest data.

Summary of Dry-Aging Tests - In general, dry aging did not seriously effect the important properties of the foam such as flame spread and flame penetration. The better foams withstood dry aging in good shape.

Selection of the "10 Best" Candidate Foams for Further Evaluation - The program called for the selection of 10 foam candidates for further testing from those having undergone the water immersion testing and evaluation. The immersion tests, however, produced no results for any of the candidates that on their own were cause for rejection. Consequently, the selection of the "10 Best" was made on the flame spread data for the virgin samples.

Although somewhat arbitrary, in order to include the full spectrum of formulations for additional testing, the "10 Best" selected foams, by item number and source, were as follows:

Item no	Source
5	Callery Chemical/Mine Safety Appliances Co.
9	Cook Paint & Varnish
11	Foam Systems Co.
14	Freeman Chemical
15	Olin Corporation
17	Texas Urethanes
23	Witco Chemical
24	General Electric
25	W. R. Grace
26	Reichhold Chemical, Ltd.

This group was subjected to advanced testing to gather additional data for the final selection process. The tests were:

- flash and self-ignition temperature
- air permeability
- adhesion to common mine substrates.

Item 4, Callery Chemical Companys Rigimix E/F foam, did not rank sufficiently high to be selected as one of the "10 best foams". It has had widespread use in mines over the past 15 years, however, and was included in the advanced testing as an eleventh material, to be used as a comparison standard for the "10 best".

Ignition Temperatures

Organic materials have rather definite flash and self ignition temperatures. Ideally, foams used on stoppings should have as high ignition temperatures as possible. The lower the ignition temperature, the easier it should be to ignite the foams.

The ignition temperatures of the "10 best" foams were determined using ASTM Method D1929-77, Procedure B. The apparatus essentially consists of a vertical tube furnace containing an inner ceramic tube with an inside diameter of 3" and a length of 10". Heated air is passed up through the inner tube at a velocity of ·5ft/min. The foam sample is

lowered into the furnace at various temperatures and the sample observed for evidence of ignition for 5 minutes.

The lowest furnace temperature at which ignition occurs is called the self ignition temperature. To determine the flash ignition temperature, a small pilot flame is located at the exit of the furnace; the minimum temperature at which the gases ignite and flash back to the sample is called the flash ignition temperature.

The ASTM method was not designed for cellular plastics so certain modifications in the sample size were made. Normally, a 3/4" x 3/4" cubical sample weighing 3 ± 0.5 g is used. This is not possible with foams, so a sample 3/4" x 3/4" x 1 1/2" was used without reference to weight. In this technique, equal volumes of foam were compared. This is reasonable when it is apparent that essentially equal volumes of foam would be used on stoppings.

The ignition temperatures are shown in Table 36. The self ignition temperatures of all the urethanes were between 500-525°C. The silicone (Item 24) was only 460°C while the phenolic (Item 26) was 600°C. Our previous experience had indicated that the self ignition temperature depended more upon the generic type of foam than upon the actual composition; these data tend to confirm this.

TABLE 36 - Flash and self ignition temperatures of "10 best" foams

Item no	Foam 1676-	Ignition temperatures, °C Flash	Self
4	48-11	400	525
5	48-12	525	525
9	48-9	445	525
11	46-10	445	525
14	48-7	435	500
15	48-6	445	500
17	48-1	445	525
23	46-7	445	500
24	50-2	420	460
25	50-3	525	525
26	50-5	600	600

The flash ignition temperatures were more varied than the self ignition temperatures. Most of the flash ignition temperatures were below 450°C, but Items 5, 25 and 26 were significantly higher. Those foams having flash ignition temperatures above 500°C were also those having a flame spread index by the modified radiant panel (see Table 37) of less than 100. These data show that a flash ignition temperature in excess of 500°C is highly desirable and indicative of a low flame spread index.

TABLE 37 - Ignition temperatures and flame spread indexes

Item	Foam	Ignition temperatures, °C		Radiant panel flame spread index	
no	1676-	Flash	Self	E162	CCC-2
4	48-11	400	525	144	1367
5	48-12	525	525	2	39
9	48-9	445	525	112	645
11	46-10	445	525	68	781
14	48-7	435	500	10	696
15	48-6	445	500	12	1245
17	48-1	445	525	65	1551
23	46-7	445	500	13	1748
24	50-2	420	460	75	529
25	50-3	525	525	16	1
26	50-5	600	600	3	2

Air Permeability

A foam must be capable of stopping the flow of air to be suitable for use on stoppings. To determine its permeability to air, the leak rate of the candidate foams, applied to a porous backing, was measured at test air pressures of 1, 5 and 10 inches W.G.

One-half inch building insulation board (Celotex) was used as the porous substrate. Tests had shown that a 2' x 2' sample of uncoated Celotex had a leak rate of over 2 CFM at 0.4" W.G., well in excess of any values expected in our tests.

The test apparatus is shown in Figure 6. The top and bottom framework are fabricated of aluminum, with flanges at the seal surfaces 1/4" thick and 5/8" wide. The outside dimensions of the flanges, and thus the sample, are 2' x 2'. The samples were sealed in the 1 1/2" angle iron frame and the frame clamped in between the top and bottom framework.

Two samples of each foam candidate were prepared on the porous substrate--one at a nominal 1" thickness, and one somewhat thicker. For

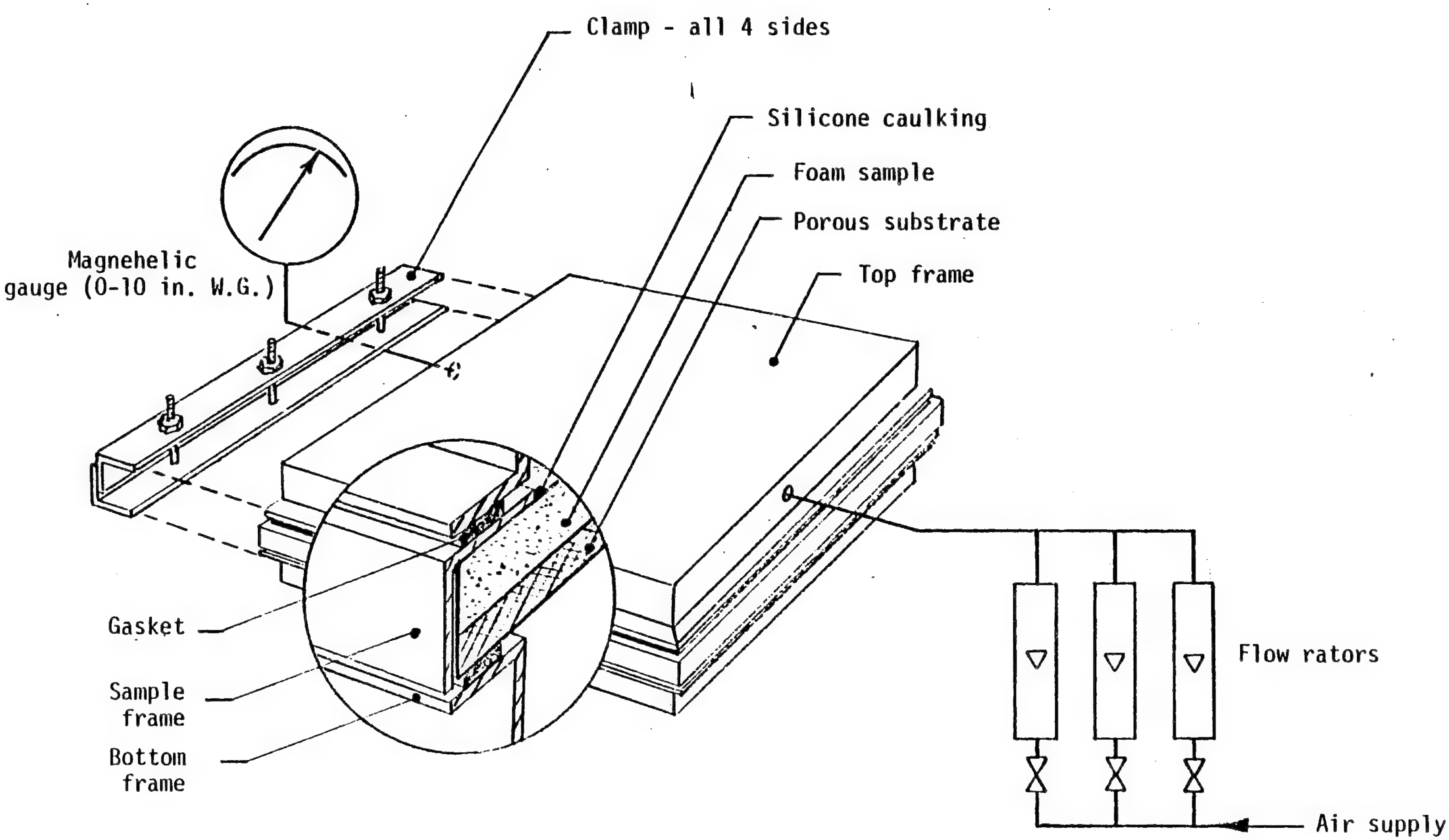


FIGURE 6 - Schematic of air permeability apparatus

the initial test, the 1" sample was sealed into the frame using silicone caulking on the edges and around the face. Total sample surface area exposure was 3.06 sq. ft. For most of the candidates, the leak rate was so low for this sample that the thicker sample was not tested. For those with a significant leak rate on the 1" sample, the thicker sample was also tested.

The results of the air permeability tests are shown in Table 38, and a comparison of the air permeability and closed cell content in Table 39. Most of the foams have very low air permeability and high closed cell content.

We expected the air permeability, for the most part, to be a direct function of the closed cell content. We would expect a closed cell foam to have very low permeability unless the cell walls were very weak and apt to rupture upon the application of pressure. Conversely, a low closed cell content was expected to have high permeability. We could not, however, predict the effect of the surface skin.

Items 25 and 26 had very low closed cell contents and very high air permeability. Item 24 had a low closed cell content and low but variable air permeability. The flexibility and high density may render this foam partially self-sealing. The low and variable permeability of Items 9 and 14 may indicate minor imperfections or a few weak membranes.

The high air permeability of Items 25 and 26 discourages their use on mine stoppings; they would not make adequate seals.

Adhesion Testing

Adhesion test samples of 9 of the "10 best" foams were prepared on the selected substrates by spraying or pouring. Five solid substrates (coal, wood, rock, concrete block and plastic coated brattice cloth) were used under four conditions: (1) dry, (2) dry and coated with rockdust, (3) wet and (4) wet, coated with rockdust. Three metal substrates were also used (1/2 inch hardware cloth, expanded metal lath and Truss Loop*. Originally, 1/2 inch, 1-inch and 2-inch wire screens were to be used as substrates, but it was soon obvious that foam samples could not be built up on the 1-inch and 2-inch screens. Expanded metal lath and Truss Loop were substituted for the 1-inch and 2-inch screens because they seemed to be practical metal backings for use in mines. Later both 3/16 inch and 1/4 inch Arco Durathene polyolefin diamond mesh net were evaluated with one foam system. No tests were conducted on the tenth sample, the phenolic foam (Item 26) due to the lack of a suitable sample. Also, its air permeability essentially excluded it from further consideration.

*Truss loop - a perforated metal lath manufactured by Bostwick Steel Lath Company, Niles Ohio - used as backing for ceramic tile, gunnite, concrete decking, etc.

TABLE 38 - Air permeability of foams

Item no	Sample 1676-	Sample thickness, in	Permeability (SCFM/100 ft^2) at P of 1" H_2O	5" H_2O	10" H_2O
Control	Celotex	0.5	121	ND	ND
		0.5	121	ND	ND
4	48-11	0.9	<.05	<.05	<.05
5	48-12	0.8	<.05	<.05	<.05
9	48-9	1.0	<.05	0.22	0.32
		1.0	<.05	<.05	<.05
11	46-10	0.6	<.05	<.05	<.05
14	48-7	0.5 - 0.8	<.05	0.05	0.11
		1.0	<.05	<.05	<.05
15	48-6	0.5	<.05	<.05	<.05
17	48-1	0.8	<.05	<.05	<.05
23	46-7	0.8	<.05	<.05	<.05
24	50-2	0.3 - 0.5	<.05	0.54	0.81
		0.5 - 0.8	<.05	<.05	<.05
		1.0	<.05	0.11	0.22
25	50-3	1.4	65	194	283
		1.5	89	242	299 (8"H_2O)
26*	50-5	1.0	16	95	181

Note: *Single 16.9 in^2 sample used
ND = No data

TABLE 39 - Comparison of closed cell content and air permeability

Item no	Sample 1676-	% Closed cell	Thickness, in (Avg)	Air permeability SCFM/100 ft^2 at P of 1" H_2O	5" H_2O	10" H_2O
4	48-11	98	0.9	<.05	<.05	<.05
5	48-12	93	0.8	<.05	<.05	<.05
9	48-9	89	1.0	<.05	.22	.32
			1.0	<.05	<.05	<.05
11	46-10	95	0.6	<.05	<.05	<.05
14	48-7	92	0.5 - 0.8	<.05	<.05	.11
			1.0	<.05	<.05	<.05
15	48-6	94	0.5	<.05	<.05	<.05
17	48-1	91	0.8	<.05	<.05	<.05
23	46-7	93	0.8	<.05	<.05	<.05
24	50-2	23	0.3 - 0.5	<.05	.54	.81
			0.5 - 0.8	<.05	<.05	<.05
			1.0	<.05	.11	.22
25	50-3	9	1.4	65	194	283
			1.5	89	242	299 (8"H_2O)
26*	50-5	1	1.0	16	95	181

Note: *Single 16.9 in^2 sample used

The rockdusted substrates were prepared by sprinkling a thin uniform layer of rockdust on the horizontal substrate until the substrate was completely hidden from view. The wet substrates were prepared by hand spraying water onto the horizontal substrates (clean or rockdusted) until the surface was saturated but not pooled with water.

The adhesion samples were prepared by spraying or pouring about one inch of foam onto the substrate and foaming a metal pull tab in place with about one inch of foam (Figure 7). The pull tabs consisted of 4-inch square perforated metal sheets with an attached eyebolt. This is basically the procedure described in the Bureau of Mines Report of Investigation 6366[2] on "Rigid Foam in Mines."

The samples were pulled on an Instron Tensile Testing machine with the foamed substrate mechanically held to the machine. The crosshead was then attached to the eyebolt and the sample pulled to failure. To make the sample size uniform, a die was prepared which cut a circle six inches in diameter while using the eyebolt as the center. Excess foam was cut from around the six inch circle to make certain the foam sample was free from the adjacent foam.

The adhesion data are shown in Table 40 along with the average values for the duplicate samples and the estimated percent of substrate exposed following the pull test. The average adhesion values are shown in Table 41 as a function of the substrate type along with the median and standard deviation. The data in Table 41 are summarized in Table 42. These data show the best adhesion was to metals, followed by concrete. The lowest adhesion was to brattice cloth. (The data for the plastic mesh are not comparable since it is only for one foam.)

These same adhesion averages are also shown in Table 43 as a function of the condition of the substrate along with the median values and standard deviation. These data are summarized in Table 44, which show the adhesion to be much better to dry than to wet substrates. This is what one would expect since the water prevents the foam from effectively reaching and adhering to the substrate.

The presence of rockdust did not adversely effect the adhesion to dry substrates. The adhesion to wetted and rockdusted substrates, on the other hand, was the poorest of all. The foams showing the best adhesion were Items 11 and 4; Item 24 showed the poorest adhesion.

Ideally, the foam should not only adhere to the substrate, but any failure in tension should be within the foam rather than at the substrate. The data in Tables 45 and 46 summarize the mode of failure as a function of both substrate (Table 45) and substrate condition (Table 46). The table notes the percent of substrate exposed at the break. Thus, the lower results indicate a desirable foam-to-foam failure rather than a foam-substrate failure. As with the actual adhesion numbers, the best adhesion (lowest percent substrate exposed) was to metal and concrete block, with plastic brattice cloth being the poorest. Similarly, the

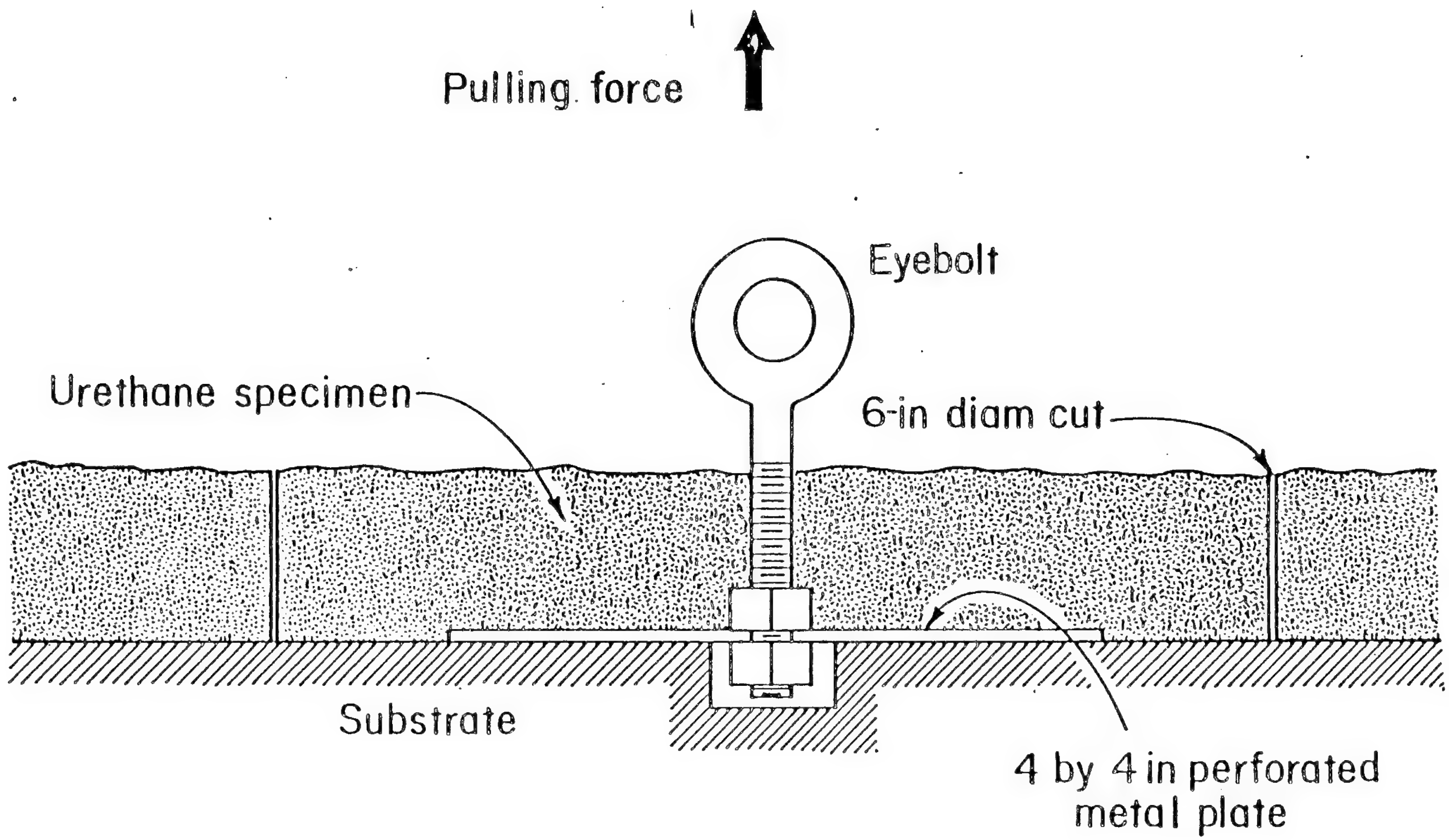


FIGURE 7 - Pull tab set up for adhesion testing

TABLE 40 - Foam adhesion test data

Item no	4			5			9			11			14		
Sample 1676-	48-11 (1)			48-12			48-9			46-10			48-7		
Substrate	lbs (2)	avg	% (3)	lbs	avg	%	lbs	avg	%	lbs	avg	%	lbs	avg	%
Coal															
Clean & dry	248	268	100	100	105	0	128	143	0	190	289	100	254	188	70 (4)
Clean & dry	288		0	110		0	158		0	388		0	121		100
Wet	40	40	100	37	44	100	156	136	0	190	205	100	85	69	100
Wet	39		100	50		30	116		60	220		0	53		100
Rockdust dry	296	255	0	110	115	0	110	109	0	324	272	75	190	138	0
Rockdust dry	212		50	120		0	108		0	220		90	85		100
Rockdust wet	10	8	100	31	16	100	38	66	100	56	48	100	20	21	100
Rockdust wet	5		100	0		100	94		100	40		100	21		100
Rock															
Clean & dry	292	246	90	110	112	0	122	132	0	308	328	100	94	104	100
Clean & dry	200		0	114		0	142		0	348		0	114		0
Wet	84	72	100	36	18	100	144	88	0	130	141	100	0	7	100
Wet	59		100	0		100	32		100	152		100	14		100
Rockdust dry	190	187	90	108	125	0	126	143	0	264	300	100	163	82	0
Rockdust dry	184		100	142		100	160		0	336		0	0		100
Rockdust wet	13	92	100	28	21	100	76	61	100	36	34	100	55	42	100
Rockdust wet	170		100	13		100	46		100	32		100	28		100

TABLE 40 - Foam adhesion test data (cont)

Item no	4			5			9			11			14		
Sample 1676-	48-11 (1)			48-12			48-9			46-10			48-7		
Substrate	lbs (2)	avg	% (3)	lbs	avg	%	lbs	avg	%	lbs	avg	%	lbs	avg	%
Concrete block															
Clean & dry	192	236	0	132	127	0	144	156	0	324	352	0	186	183	0
Clean & dry	280		0	122		0	168		0	380		0	180		50
Wet	212	246	0	66	83	90	146	144	100	158	160	100	71	66	100
Wet	280		0	100		0	142		0	162		100	60		100
Rockdust dry	352	292	0	134	145	0	118	130	0	420	408	0	276	278	0
Rockdust dry	232		0	156		0	142		0	396		0	280		0
Rockdust wet	208	181	20	36	35	100	108	114	0	104	117	100	0	0	100
Rockdust wet	154		100	34		100	120		0	130		100	0		100
Wood (oak)															
Clean & dry	208	208	0	100	121	100	122	128	100	316	304	0	0	0	100
Clean & dry	208		0	142		0	134		0	292		0	0		100
Wet	80	81	100	34	20	100	164	108	0	288	270	100	62	41	100
Wet	82		100	6		100	52		100	252		100	20		100
Rockdust dry	312	292	0	122	124	0	170	151	0	260	274	100	80	103	100
Rockdust dry	272		0	126		100	132		0	288		0	126		100
Rockdust wet	51	57	100	0	0	100	118	83	0	126	126	100	0	0	100
Rockdust wet	63		100	0		100	48		100	126		100	0		100

TABLE 40 - Foam adhesion test data (cont)

Item no	4			5			9			11			14		
Sample 1676-	48-11[1]			48-12			48-9			46-10			48-7		
Substrate	lbs[2]	avg	%[3]	lbs	avg	%	lbs	avg	%	lbs	avg	%	lbs	avg	%
Brattice cloth															
Clean & dry	130	124	75	81	71	100	92	97	70	132	133	75	73	69	100
Clean & dry	118		75	61		100	101		60	134		80	64		100
Wet	78	73	100	24	22	100	48	37	100	46	46	100	0	0	100
Wet	67		100	19		100	25		100	46		100	0		100
Rockdust dry	148	145	75	65	63	100	72	85	90	102	101	100	56	58	100
Rockdust dry	142		75	60		80	97		60	100		100	59		100
Rockdust wet	80	51	100	0	0	100	56	45	100	36	35	100	0	0	100
Rockdust wet	22		100	0		100	34		100	34		100	0		100
1/2" Hardware cloth	198	205	0	111	109	100	118	110	0	204	228	80	118	138	90
1/2" Hardware cloth	212		66	107		100	102		0	255		80	158		20
Expanded metal lath	192	182	66	122	123	60	126	133	0	312	348	75	204	208	50
Expanded metal lath	172		50	124		60	140		60	384		70	212		60
Truss loop	118	107	100	114	103	100	101	106	80	116	146	100	84	96	85
Truss loop	96		100	91		100	110		70	176		100	108		85
3/16" Plastic mesh	166	171	70	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
3/16" Plastic mesh	176		95	ND		ND	ND		ND	ND		ND	ND		ND
1/4" Plastic mesh	124	135	100	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1/4" Plastic mesh	146		90	ND		ND	ND		ND	ND		ND	ND		ND

Notes: (1) For information only; not included in "10 best" selection.

(2) Total pounds on 6" circle (28.3 in).

(3) % of substrate surface exposed during test.

(4) Lifted layer of substrate.

ND = No data

TABLE 40 - Foam adhesion test data (cont)

Item no	15			17			23			24			25		
Sample 1676-	48-6			48-1			46-7			50-2			50-3		
Substrate	lbs	avg	%	lbs	avg	%	lbs	avg	%	lbs	avg	%	lbs	avg	%
Coal															
Clean & dry	116	92	0	190	172	100	67	112	100	71	62	70	120	96	0
Clean & dry	68		100	154		100	156		100	52		100	72		60 (4)
Wet	118	113	100	82	94	100	71	111	95	3	15	100	124	124	0
Wet	108		100	105		100	150		80	27		100	124		0
Rockdust dry	172	206	0	70	172	50	196	158	0	73	48	70	140	140	0
Rockdust dry	240		0	274		0	120		0	22		90	ND		ND
Rockdust wet	31	23	100	43	55	100	86	66	100	5	7	100	70	103	100
Rockdust wet	15		100	67		100	46		100	8		100	136		0
Rock															
Clean & dry	87	88	100	172	141	0	208	147	10	77	126	80	100	97	0
Clean & dry	88		0	110		0	86		0	174		10	94		0
Wet	0	0	100	103	83	100	88	82	100	260	130	50	104	92	0
Wet	0		100	62		100	75		100	0		100	80		0
Rockdust dry	186	194	0	208	155	100	160	165	100	220	110	10	120	95	0
Rockdust dry	202		0	102		100	170		0	0		100	70		0
Rockdust wet	30	28	100	45	44	100	0	0	100	45	23	100	104	107	0
Rockdust wet	26		100	43		100	0		100	0		100	110		0

TABLE 40 - Foam adhesion test data (cont)

Item no	15			17			23			24			25		
Sample 1676-	48-6			48-1			46-7			50-2			50-3		
Substrate	lbs	avg	%	lbs	avg	%	lbs	avg	%	lbs	avg	%	lbs	avg	%
Concrete block															
Clean & dry	140	169	0	188	195	100	172	198	0	115	113	100	86	119	0
Clean & dry	198		0	202		100	224		0	110		100	152		0
Wet	102	108	100	155	125	100	136	79	100	25	43	100	0	0	100
Wet	114		100	95		0	21		100	61		100	0		100
Rockdust dry	256	240	0	292	308	0	264	228	0	0	0	100	6	21	100
Rockdust dry	224		0	324		0	192		0	0		100	35		100
Rockdust wet	46	59	100	102	95	100	0	0	100	0	0	100	68	34	100
Rockdust wet	72		100	87		100	0		100	0		100	0		100
Wood (oak)															
Clean & dry	198	153	100	140	110	100	244	230	0	134	136	0	152	146	0
Clean & dry	108		100	79		100	216		100	138		0	140		0
Wet	116	122	100	77	74	100	20	44	100	27	48	100	88	120	0
Wet	128		100	70		100	68		100	68		100	152		0
Rockdust dry	166	239	100	272	252	60	220	203	0	3	29	100	160	163	0
Rockdust dry	312		0	232		60	186		100	54		100	166		0
Rockdust wet	0	0	100	0	0	100	0	0	100	0	0	100	140	107	0
Rockdust wet	0		100	11		100	0		100	0		100	74		0

TABLE 40 - Foam adhesion test data (cont)

Item no	15			17			23			24			25		
Sample 1676-	48-6			48-1			46-7			50-2			50-3		
Substrate	lbs	avg	%	lbs	avg	%	lbs	avg	%	lbs	avg	%	lbs	avg	%
Brattice cloth															
Clean & dry	140	140	60	160	122	100	142	140	70	0	0	100	180	172	0
Clean & dry	140		70	83		70	138		75	0		100	164		0
Wet	42	39	100	41	37	100	26	27	100	0	0	100	154	144	0
Wet	35		100	33		100	28		100	0		100	134		0
Rockdust dry	130	119	100	92	89	0	136	126	60	0	0	100	56	72	100
Rockdust dry	108		100	85		0	116		50	0		100	87		100
Rockdust wet	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100
Rockdust wet	0		100	0		100	0		100	0		100	0		100
1/2" Hardware cloth	150	229	90	246	235	75	224	220	70	85	81	100	98	105	0
1/2" Hardware cloth	448		0	224		0	216		70	77		100	112		0
Expanded metal Lath	224	222	10	260	291	0	260	215	50	132	128	0	140	136	0
Expanded metal Lath	220		70	322		0	170		70	124		0	132		0
Truss loop	132	146	90	234	216	80	152	158	100	61	58	100	154	145	0
Truss loop	162		90	198		80	164		90	55		100	136		0

TABLE 41 - Foam adhesion data as a function of substrate

Item no		4	5	9	11	14	15	17	23	24	25		Std
Sample-1676		48-11	48-12	48-9	46-10	48-7	48-6	48-1	46-7	50-2	50-3	Avg	dev
Substrate	Condition												
Brattice cloth	Clean & dry	124	71	97	133	69	140	122	140	0	172	107	50
	Rockdust & dry	145	63	85	101	58	119	89	126	0	72	86	41
	Wet	73	22	37	46	0	39	37	27	0	144	42	41
	Rockdust & wet	51	0	45	35	0	0	0	0	0	0	13	23
	Avg	98	39	66	79	32	74	62	73	0	97	62	NA
	Std dev	44	32	29	43	34	62	54	65	0	72	54	54
Coal	Clean & dry	268	105	143	289	188	92	172	112	62	96	153	87
	Rockdust & dry	255	115	109	272	138	206	172	158	48	140	162	83
	Wet	40	44	136	205	69	113	94	111	15	124	95	56
	Rockdust & wet	8	16	66	48	21	23	55	66	7	103	41	35
	Avg	142	70	114	204	104	109	123	112	33	112	112	NA
	Std dev	130	46	38	118	82	74	78	52	29	29	83	83
Concrete block	Clean & dry	236	127	156	352	183	169	195	198	113	119	185	73
	Rockdust & dry	292	145	130	408	278	240	308	228	0	21	205	129
	Wet	246	83	144	160	66	108	125	79	43	0	105	71
	Rockdust & wet	181	35	114	117	0	59	95	0	0	34	63	62
	Avg	239	98	136	259	132	144	181	126	39	43	140	NA
	Std dev	62	47	19	133	114	75	90	106	50	55	104	104
Rock	Clean & dry	246	112	132	328	104	88	141	147	126	97	152	81
	Rockdust & dry	187	125	143	300	82	194	155	165	110	95	156	79
	Wet	72	18	88	141	7	0	83	82	130	92	71	67
	Rockdust & wet	92	21	61	34	42	28	44	0	23	107	45	42
	Avg	149	69	106	201	59	77	106	98	97	98	106	NA
	Std dev	90	55	48	130	60	80	59	77	106	16	84	84

TABLE 41 - Foam adhesion data as a function of substrate (cont)

Item no		4	5	9	11	14	15	17	23	24	25		Std.
Sample 1676-		48-11	48-12	48-9	46-10	48-7	48-6	48-1	46-7	50-2	50-3	Avg	dev
Substrate	Condition												
Wood	Clean & dry	208	121	128	304	0	153	110	230	136	146	154	81
	Rockdust & dry	292	124	151	274	103	239	252	203	29	163	183	87
	Wet	81	20	108	270	41	122	74	44	48	120	93	74
	Rockdust & wet	57	0	83	126	0	0	6	0	0	107	38	52
	Avg	160	66	118	244	36	129	110	119	53	134	117	NA
	Std dev	103	62	46	75	48	102	98	107	57	34	67	67
Hardware cloth	dry	205	109	110	228	138	299	235	220	81	105	173	87
Metal lath	dry	182	123	133	348	208	222	291	215	128	136	199	76
Truss loop	dry	107	103	106	146	96	146	216	158	58	145	128	45
3/16" Plast. mesh	dry	171	ND	ND	ND	ND	ND	ND	ND	ND	ND	171	ND
1/4" Plast. mesh	dry	135	ND	ND	ND	ND	ND	ND	ND	ND	ND	135	ND
	Avg	160	112	116	241	147	223	247	198	89	129	167	NA
	Std dev	38	12	15	97	53	117	42	42	32	20	76	76
All	Avg	158	74	109	208	82	122	133	118	50	101	115	NA
	Std dev	89	49	40	116	81	93	90	84	63	51	89	89

Note: NA = Not applicable
ND = No data

TABLE 42

Summary - foam adhesion based on substrate (lbs)

Item no	Sample 1676-	Brattice cloth	Coal	Concrete block	Rock	Wood	Metal	Plastic	Avg
4*	48-11	98	142	239	149	160	165	153	158
5	48-12	39	70	98	69	66	112	ND	74
9	48-9	66	114	136	106	118	116	ND	109
11	46-10	79	204	259	201	244	241	ND	208
14	48-7	32	104	132	59	36	147	ND	82
15	48-6	74	109	144	77	129	223	ND	122
17	48-1	62	123	181	106	110	247	ND	133
23	46-7	73	112	126	98	119	198	ND	118
24	50-2	0	33	39	97	53	89	ND	50
25	50-3	97	112	43	98	134	129	ND	101
Avg		62	112	140	106	117	167	153	115

Note: *For information only; not included in "10 best" selection.
ND = No data

TABLE 43 - Foam adhesion data as a function of substrate condition

Item no		4	5	9	11	14	15	17	23	24	25		Std
Sample 1676-		48-11	48-12	48-9	46-10	48-7	48-6	48-1	46-7	50-2	50-3	Avg	dev
Condition	Substrate												
Clean & dry	Brattice cloth	124	71	97	133	69	140	122	140	0	172	107	50
	Coal	268	105	143	289	188	92	172	112	62	96	153	87
	Concrete block	236	127	156	352	183	169	195	198	113	119	185	73
	Rock	246	112	132	328	104	88	141	147	126	97	152	81
	Wood	208	121	128	304	0	153	110	230	136	146	154	81
	Avg	216	107	131	281	109	128	148	165	87	126	150	NM
	Std dev	61	24	24	95	81	44	44	59	58	37	78	78
	Hardware cloth	205	109	110	228	138	299	235	220	81	105	173	87
	Metal lath	182	123	133	348	208	222	291	215	128	136	199	76
	Truss loop	107	103	106	146	96	146	216	158	58	145	128	45
	Plastic mesh	153	ND	ND	ND	ND	ND	ND	ND	ND	ND	153	23
	Avg	160	112	116	241	147	223	247	198	89	129	166	NM
	Std dev	38	12	15	97	53	117	42	42	32	20	76	76
Rockdust & dry	Brattice cloth	145	63	85	101	58	119	89	126	0	72	86	41
	Coal	255	115	109	272	138	206	172	158	48	140	162	83
	Concrete block	292	145	130	408	278	240	308	228	0	21	205	129
	Rock	187	125	143	300	82	194	155	165	110	95	156	79
	Wood	292	124	151	274	103	239	252	203	29	163	183	87
	Avg	234	114	124	271	132	200	195	176	37	93	158	NM
	Std dev	72	31	29	108	95	61	98	46	69	57	96	96
All dry	Avg	203	111	125	268	126	178	189	177	68	115	156	NM
	Std dev	65	24	23	98	80	80	78	50	62	44	94	94

TABLE 43 - Foam adhesion data as a function of substrate condition (cont)

Item no		4	5	9	11	14	15	17	23	24	25		Std
Sample 1676-		48-11	48-12	48-9	46-10	48-7	48-6	48-1	46-7	50-2	50-3	Avg	dev
Condition	Substrate												
Clean & wet	Brattice cloth	73	22	37	46	0	39	37	27	0	144	42	41
	Coal	44	44	136	205	69	113	94	111	15	124	95	56
	Concrete block	246	83	144	160	66	108	125	79	43	0	105	71
	Rock	72	18	88	141	7	0	83	82	130	92	71	67
	Wood	81	20	108	270	41	122	74	44	48	120	93	74
	Avg	103	37	103	164	37	76	82	68	47	96	81	NM
	Std dev	78	29	56	79	33	51	33	47	79	56	66	66
Rockdust & wet	Brattice cloth	51	0	45	35	0	0	0	0	0	0	13	23
	Coal	8	16	66	48	21	23	55	66	7	103	41	35
	Concrete block	181	35	114	117	0	59	95	0	0	34	63	62
	Rock	92	21	61	34	42	28	44	0	23	107	45	42
	Wood	57	0	83	126	0	0	6	0	0	107	38	52
	Avg	78	14	74	72	12	22	40	13	6	70	40	NM
	Std dev	74	16	34	44	19	24	37	29	14	54	47	47
All wet	Avg	90	26	88	118	24	49	61	41	26	83	61	NM
	Std dev	75	26	48	78	29	48	41	47	59	55	61	61
All	Avg	158	74	109	208	82	122	133	118	50	101	115	NM
	Std dev	93	49	40	116	81	93	90	84	63	51	89	89

Note: ND = No data
NM = Not meaningful

TABLE 44
Summary - foam adhesion based on condition (lbs)

Item no	Sample 1676-	Clean dry	Dusty dry	All dry	Clean wet	Dusty wet	All wet	Avg
4	48-11	197	234	203	103	78	90	158
5	48-12	109	114	111	37	14	26	74
9	48-9	126	124	125	103	74	88	109
11	46-10	266	271	268	164	72	118	208
14	48-7	123	132	126	37	12	24	82
15	48-6	164	200	178	76	22	49	122
17	48-1	185	195	189	82	40	61	133
23	46-7	177	176	177	68	13	41	118
24	50-2	88	37	68	47	6	26	50
25	50-3	127	93	115	96	70	83	101
Avg		156	158	156	81	40	61	115

TABLE 45
Summary - % substrate exposed as a function of substrate

Item no	Sample 1676-	Brattice cloth	Coal	Concrete block	Rock	Wood	Metal	Plastic	Avg
4	48-11	88	69	15	85	50	64	90	64
5	48-12	98	41	36	63	75	87	ND	66
9	48-9	85	33	13	38	38	35	ND	40
11	46-10	94	71	50	75	63	84	ND	72
14	48-7	100	84	56	75	100	65	ND	81
15	48-6	91	63	50	63	88	58	ND	69
17	48-1	71	81	63	75	90	39	ND	71
23	46-7	82	72	50	64	75	75	ND	69
24	50-2	100	91	100	69	75	67	ND	84
25	50-3	50	20	75	0	0	0	ND	25
Avg		86	62	51	61	65	43	90	64

Note: ND = No data

TABLE 46

Summary - % substrate exposed as a function of substrate condition

Item no	Sample 1676-	Clean dry	Dusty dry	All dry	Clean wet	Dusty wet	All wet	Avg
4	48-11	55	39	49	80	92	86	64
5	48-12	51	38	46	82	100	91	66
9	48-9	28	15	23	56	70	63	40
11	46-10	54	57	55	90	100	95	72
14	48-7	69	60	66	100	100	100	81
15	48-6	55	30	45	100	100	100	69
17	48-1	63	37	53	90	100	95	71
23	46-7	57	31	47	98	100	99	69
24	50-2	66	87	74	95	100	98	84
25	50-3	4	44	18	20	50	35	25
Avg		50	44	48	81	91	86	64

adhesion to dry substrates was better than to wet. Although Item 4 gave high pull test values with plastic mesh, the actual adhesion to the plastic surface was poor, as evidenced by the 90 percent surface exposed. The high pull test values were obviously due to interlocking of the cured foam around the plastic-coated wires of the substrate.

The adhesive properties of the foams were arranged into groups such that Group A was the best and Group E the poorest. These results are shown in Table 47.

While these data are interesting, the important point to keep in mind is that the foam need only to maintain adhesion to the substrate to be an effective sealant. To our knowledge, the "pull" value that is

TABLE 47
Ranking of adhesive values by item number as function of substrates

Group	Dry substrates	Wet substrates	Dry metal substrates	All substrates
A	11	11	11 17	11
B	4	4 9 25	15	4 17
C	15 17 23	15 17	4 14 23	9 15 23 25
D	5 9 14 25	23	5 9 25	5 14
E	24	5 14 24	24	24

adequate to maintain adhesion has not been properly defined. Mitchell,[3] suggested 200 lbs for dry surfaces and 100 lbs for wet surfaces with no

[3]Mitchell, D. W., Nagy, J. and Murphy, E. M. Rigid Foam for Mines. BuMines RI 6366, pp 12-3.

failure at the foam-substrate interface. Mitchell's data, however, were obtained with a spring scale on a pull tab with an undefined pull area and not limited to a 6" diameter circle.

Our data show that a pull of 20 lbs or less was obtained with about 16% of the samples, of which only 23% were dry substrates. Thus, most of the low pulls were on the wet substrates. Moreover, most of the candidates are polyurethanes, and it is characteristic of polyurethanes in general to have low adhesion to wet substrates. This is not only caused by the barrier formed by the water but also by the water reacting with the isocyanate component of the system to release carbon dioxide which tends to blow the foam off the substrate.

Theoretically, the foam needs only sufficient adhesion to support its own weight. Even a pull of 1 lb should be more than sufficient. Thus, although the data can be used to compare adhesion of the candidates with the various substrates, we conclude that all of the foams showed adequate adhesion except to wet substrates and plastic coated brattice cloth.

SAFETY

The application of an organic foam can produce hazardous vapor concentrations of raw or unreacted components, solvents, catalysts, etc., irritating to the eyes and respiratory tract, or result in minor or severe skin irritations from contacts with liquids or sprays. The use of protective goggles, rubber aprons and gloves and organic cartridge vapor respirators is generally recommended. The application of some foams present greater hazards than others. This section reviews the hazards of those foam types being considered.

Rigid Polyurethane Foams

Twenty of the 27 foams evaluated, and seven of the "10 best" foams were conventional rigid polyurethane spray foams. These foams are prepared by mixing two liquid materials commonly called the "A" and "B" components. The "A" component contains a polymeric isocyanate. The "B" component contains polyalcohols (polyols), blowing agent, catalyst, surfactant, and perhaps, a fire retardant additive.

"A" Component - The "A" component is a mixture of polymeric isocyanates. NIOSH has recommended that all isocyanates have a TLV of 0.02 ppm and a TWA of 0.005 ppm in air. With respect to polymeric isocyanates, their data was obtained using polymethylene diisocyanate (MDI). Actually, MDI comprises about 50% of the isocyanate; the remainder consists of higher molecular weight polyisocyanates having lower vapor pressure than MDI. This reduces the vapor hazard.

Tests have shown that the TLV level above an open container of polymeric isocyanate is not reached until it is heated to 110-120°F. Such temperatures are seldom reached in mine working areas.

The oral and dermal toxicity of the polymeric isocyanate is also low (LD_{50} = >10 g/kg).

Tests have usually not detected isocyanate vapors in the vicinity of a spray operation when polymeric isocyanates were used. They did, however, find small droplets of polyisocyanates. These settled out or reacted with the moisture vapor to form solid ureas in about three minutes.

"B" Component - The "B" component contains monofluorotrichloromethane (CCl_3F, Fluorocarbon-11) as the blowing agent, which is a low boiling liquid (75°F) comprising about 25% of the component. It has a TLV of 1000 ppm. The catalyst may contain a tertiary amine and/or a small mount of metal catalyst (typically an organo-tin or organo-lead compound). The amines may be slightly irritating to eyes and respiratory tract. The metal catalysts are usually present at such low levels that they can hardly be detected.

The polyol itself is generally not considered to be a hazard. The surfactant is usually a high molecular weight silicone-based block copolymer, which is considered non-toxic.

Summary - Only the polyisocyanate and the blowing agent of the polyurethane foam formulations have been assigned TLV's. All other ingredients are considered to be nontoxic but could cause an allergic reaction to spray.

Industry-wide experience in spraying millions of pounds of polyurethane foam has shown that no particular toxicity hazard exists when the spray operator and people in the vicinity of the spray operation are wearing appropriate breathing apparatuses; normally, supplied-air masks are used. Simple protective clothing and safety glasses usually serve to protect the operators from contact. Foams cure within a few minutes, and once cured, emit no significant vapors.

Protection for mine personnel downstream of a spraying operation is dependent on the magnitude of the spray operation, amount of ventilation air and proximity of personnel. Spraying a stopping several crosscuts back from the face, in most mine ventilation would sufficiently dilute component vapors to a safe level. Where this is to be a routine operation, however, vapor concentrations should be checked to determine protection requirements.

Isocyanurate Foams

Three of the candidate foams were isocyanurate foams. They are prepared from an excess of polymeric isocyanate reacted with a small amount of polyol. The safety hazards of these foams are the same as for the rigid polyurethane foams.

Flexible Polyurethane Foam

One candidate foam was a highly solids-loaded, flexible polyurethane-based foam (Hypol, Item 25). The isocyanate component is a Toluene diisocyanate (TDI) prepolymer which has a vapor pressure about that of pure MDI. However, the TDI prepolymer is very viscious and must be heated to be suitable for spraying. At the elevated temperatures, the isocyanate component could be above the TLV in the vapor phase. This is uncertain and was not measured.

The other component of the Hypol foam is an aqueous suspension of mainly inorganic solids. None of these components are hazardous.

Overall, the TDI prepolymer for the Hypol candidate is slightly more hazardous than the polymeric isocyanates used in the rigid polyurethane and isocyanurate foams. The added risk, however, is minor.

Silicone Foams

Two foam candidates were silicone based (Items 3 and 24). No known hazards are associated with their use.

Phenolic Foam

One candidate foam (Item 26), a rigid phenolic, was supplied to us as boardstock without any information relative to its liquid precursors.

In the past, one component of the phenolics has been a phenol-formaldehyde prepolymer, which was reacted with an acidic material to form the foam. The phenolic prepolymers are not usually hazardous. The catalyst may be somewhat corrosive due to its acidic properties.

The candidate phenolic foam appears to be a new type, and thus the older stereotypes may not apply. We do not, however, expect the components to have any particularly hazardous properties.

Summary

The information available about the potentially hazardous materials present in the foams tested are summarized in Table 48. While this list looks rather formidable, experience has shown that the foams can be prepared without any significant hazards, when reasonable precautions are taken.

SELECTION OF "FINAL 2" FOAMS FOR IN-MINE TESTING

The objective of Phase II of this program was to select two foam candidates considered the best of the group for in-mine testing as stopping sealants. Twenty-seven candidates were initially selected from an industry-wide survey of promising foams and through a series of tests

TABLE 48
Hazardous components of foam systems

Item no	Foam 1676-	Isocyanate	$CFCl_3$	Catalysts: Amines	Catalysts: Heavy metals
1	48-2	Polymeric	Yes	Probable	Probable
2	48-13	Polymeric	Yes	Probable	Probable
3	50-1	None	None	ND	ND
4	48-11	Polymeric	Yes	Yes	Yes
5	48-12	Polymeric	Yes	Yes	Yes
6	46-4	Polymeric	Yes	Yes	ND
7	46-3	Polymeric	Yes	Yes	Yes
8	46-1	Polymeric	Yes	Yes	Yes
9	48-9	Polymeric	Yes	ND	ND
10	48-10	Polymeric	Yes	Yes	ND
11	46-10	Polymeric	Yes	Probable	ND
12	46-11	Polymeric	Yes	Probable	ND
13	46-12	Polymeric	Yes	Probable	ND
14	48-7	Polymeric	Yes	Yes	ND
15	48-6	Polymeric	Yes	Probable	Yes
16	46-6	Polymeric	Yes	Probable	ND
17	48-1	Polymeric	Yes	Probable	ND
18	48-8	Polymeric	Yes	Probable	ND
19	46-5	Polymeric	Yes	Probable	ND
20	46-9	Polymeric	Yes	Probable	ND
21	46-13	Polymeric	Yes	Probable	ND
22	46-8	Polymeric	Yes	Probable	ND
23	46-7	Polymeric	Yes	Probable	ND
24	50-2	None	None	ND	ND
25	50-3	TDI prepolymer	None	Yes	No
26	50-5	None	ND	ND	ND
27	50-4	Polymeric	Yes	Probable	Probable

Note: ND = No data

narrowed to 16, and finally to the "10 best". These 10 were then subjected to further testing and evaluation, including possible application problems or hazards, and the final 2 candidates selected for testing.

The initial selection of the "Final 2" candidates was based on the merits of the foams. Before the in-mine tests were conducted, however, the commercial availability of the majority of top candidates became questionable when the manufacture of a component, common to the five leading urethane formulations, was discontinued on a large scale because of insufficient sales. This necessitated a reevaluation and reselection. Both selections and the logic behind them are presented for the record.

The data used for selecting the "Final 2" from the list of the "10 best" candidates are summarized in Table 49. The table does not include data from all tests conducted on the program, but includes only data from those tests which proved to be definitive; that is from which a merit ranking could be established.

Initial Selection of "Final 2" Candidates

Item 5, Callery's X-156, and item 15, were initially selected from the "10 best" for in-mine testing. Three candidates, Items 5, 25, and 26, stand out on the basis of exceptionally low flame spread index values by both the ASTM E162 and the more severe E162-CCC-2 test. Of these, however, Items 25, the Hypol-based foam, and Item 26, the phenolic, have high air permeability values, which make them unsuitable as air stopping sealants. Their high weight loss following water immersion and dry-aging may also portend problems for long-term stability. Item 5, therefore, was selected from this group.

Three more candidates, Items 14, 15 and 23, are grouped together as having lower flame spread values than the remaining, and since most all other test values are equivalent, the selection of the other candidate for the "Final 2" should logically come from one of these.

These three candidates are essentially equivalent and the selection of one for in-mine testing does not necessarily mean an apparent superiority for it over the others. Item 15 was selected on the basis of (1) overall low flame spread values even after water immersion, a condition likely prevalent in mines, and (2) lower viscosities for the components, which may make for easier application under all mine conditions.

Secondary Selection of "Final 2" Candidates

The unavailability of a polyol used in the formulation of the leading candidates, including the two initially selected for in-mine testing, resulted in the selection of Item 11 to replace Item 15. Because of insufficient market potential, Olin Corporation, the supplier of Thermolin RF 230, decided to stop production. If available at all in limited production, the polyol would be significantly more expensive, probably more than doubling the cost of the formulation.

TABLE 49
Summary of essential foam data

Item no	5	9	11	14	15	17	23	24	25	26
Sample 1676-	48-12	48-9	46-10	48-7	48-6	48-1	46-7	50-2	50-3	50-5
Tests										
1. Flame spread index										
a. E162, Virgin	2	112	68	10	12	65	13	75	16	3
, After H_2O immersion	3	176	111	15	10	56	33	85	5	5
, After dry aging	2	189	101	14	10	59	8	103	5	3
b. E162-CCC-2, Virgin	39	645	781	696	1245	1551	1748	529	1	3
, After H_2O immersion	61	819	1628	1563	1493	1862	1612	103	9	2
, After dry aging	1	1054	1162	1212	1028	2374	949	97	8	8
2. Flame penetration time										
a. Virgin	1000+	875+	743	1000+	1000+	758	1000+	914+	1000+	116
b. After dry aging*	941+	7?	6?	732	1000+	805+	1000+	587	1000+	113
3. Ignition, °C (D-1929)										
a. Flash	525	445	445	435	445	445	445	420	525	600
b. Self	525	525	525	500	500	525	500	460	525	600
4. Permeability, SCFM/100 Ft^2 @ 10" H_2O	<0.05	0.32	<0.05	0.11	<0.05	<0.05	<0.05	0.81	299	181
5. Adhesion, lbs pull	74	109	208	82	122	133	118	50	101	ND
6. Density, lbs/Ft^2	2.03	2.22	2.11	2.02	2.40	2.20	2.13	26.8	13.6	2.43
7. Compressive, psig @ 10%	22	31	21	23	31	23	23	2	2	7
8. Weight change, g.										
a. After H_2O immersion	-0.2	-0.8	-0.2	-0.1	0.0	-0.2	0.1	-1.5	-37	-8
b. After dry aging	-2.5	-3.5	-2.4	-1.1	-1.4	-1.0	-1.1	-18.4	-20.3	-11.3
9. Area change, %										
After H_2O immersion	0.2	0.0	-2.4	0.6	0.6	0.1	0.4	ND	ND	-0.9
10. Closed cell, %	93	89	95	92	94	91	93	23	9	1
Reason for rejection, test	None	1,4	1	2b,4	None	1	1	1,2b,4,8b,10	4,8,10	4,8,10

Note: *Values having ? after them are believed to be grossly erroneous; they were ignored.
ND = No data

Olin's Thermolin RF 230 is used in Callery Chemical Company's X-156. Moreover, a survey of suppliers of the remaining six urethane candidates showed that it was also a component in four of these. Those candidates containing the polyol ranked 1 through 5 by our testing, which says something for the fire retarding property contribution by the polyol. Since the candidate formulations were not known prior to the testing, the fact that the five candidates containing this polyol were the top five ranked also says something for the validity of the selection process and testing procedures.

Since material had already been purchased for the in-mine testing of X-156, this candidate (Item 5) was retained in the "Final 2". For the second candidate, Item 11 (Foam Systems' FS-24), which was sixth ranked of the urethanes, was selected. Although lower ranked than the candidates bypassed by E162, it did show more favorable data than three of these by E162-CCC-2, and had excellent adhesion test data.

FOAM COSTS

As previously stated, estimating the total "in-place" cost of a foam stopping is extremely difficult. The cost is much more dependent upon the frequency and the timing of the foaming operation than upon the cost of the chemicals and equipment. Hence, our discussion will be limited primarily to those predictable costs.

Chemicals

The chemicals from which the foam is made varied in price from \$0.56 to \$9.30 per pound (as of summer 1980). These costs are shown in Table 50 along with the estimated chemical cost per square foot of foam. The \$9.30 cost of Item 1 seems high, but it is unique in that it is a completely self-contained unit requiring no equipment; one person can both transport and operate the unit containing this foam. If the unit is not completely used (100-120 board feet), the cost would naturally increase.

Items 3 and 24 are rather expensive silicone foams. Their high density also raises the cost of material needed. The other "10 best" foams cost from \$0.59 to \$2.00 per pound or \$0.10 to \$0.67 per square foot.

The two foams selected for field testing (Items 5 and 15) cost \$1.11 to \$2.00 per pound, or \$0.22 to \$0.33 per square foot of one inch thick foam.

Equipment

All but Item 1 require some sort of pumping, metering and mixing equipment. The high viscosity components (Items 3, 24 and 25) would probably require heated equipment. The highly-filled foam (Item 25) would require extra equipment to make certain the solids were uniformly

TABLE 50
Material costs of applied foams

Item no	Cost,* $/lb	Use density,* lb/cu ft	Thickness used, in	Theoretical cost, $/ft
1	9.30	(2.2)	1.0	1.71
2	1.75	(2.2)	1.0	0.32
3	5.15	(20)	1.0	8.58
			0.5	4.29
			0.25	2.15
4	1.35	2.2	1.0	0.25
5	2.00	2.0	1.0	0.33
6	1.18	(2.2)	1.0	0.22
7	1.18	(2.2)	1.0	0.22
8	1.13	(2.2)	1.0	0.21
9	1.01	2.2	1.0	0.19
10	0.95	(2.2)	1.0	0.17
11	1.24	2.1	1.0	0.22
12	1.18	(2.2)	1.0	0.22
13	1.21	(3.0)	1.0	0.30
14	1.10	2.0	1.0	0.18
15	1.11	2.4	1.0	0.22
16	1.06	(2.2)	1.0	0.19
17	1.75	2.2	1.0	0.32
18	1.20	2.2	1.0	0.22
19	1.16	2.0	1.0	0.19
20	0.88	(2.2)	1.0	0.16
21	1.07	2.4	1.0	0.21
22	1.14	2.2	1.0	0.21
23	1.16	2.1	1.0	0.20
24	4.50	26.8	1.0	10.05
			0.5	5.03
			0.25	2.51
25	0.59	13.6	1.0	0.67
			0.5	0.33
			0.25	0.17
26	(1.00)	2.2	1.0	(0.10)
27	1.25	(2.5)	1.0	0.26

Note: *Figure in brackets are estimated.

dispersed. All other foams should be handled with moderately priced equipment using air-operated, double-acting piston pumps for both pumping and metering in conjuction with a suitable internally mixed spray gun. Such equipment is available at a cost varying from about $8000-$10,000.

The suggested equipment can be operated by one man, but the bulk and weight require extra manpower for handling and transporting. It also requires a certain amount of maintenance in order to prevent the isocyanate component from hardening in the pumps, lines, and gun. A few minutes a day is adequate for equipment that is used properly and fairly often. If the equipment is to be used infrequently, it must be cleaned out completely after each session. Hence, the more the equipment is used, the lower the maintenance costs per stopping. With proper care, a spray unit should last for over 10 years with only routine cleaning and packing replacement.

Manpower

This is the hardest cost to estimate. As mentioned previously, one person can operate the unit, but other manpower will be required to move the equipment and liquid components in the mine unless the unit and chemicals are mounted on a mechanized or motorized unit.

A stopping can be sealed in 5-10 minutes, but the time required to move the equipment to and from the work site must also be included.

Normal maintenance on a frequently used unit may require only about 30 minutes per day. Maintenance activties and clean out of an infrequently used unit may require one man day. Overhaul and major repairs should not be frequent if the equipment is properly maintained. Poor maintenance will cause the cost to escalate rapidly.

IN-MINE TESTING

The "final 2" foam candidates selected on the basis of all previous testing were used as stopping sealant materials for an in-mine test program. The contract requirements were for the design, construction, and testing of 20 stoppings--ten using foam as the main air barrier, and ten in which foam is the joint and perimeter seal for another barrier material. Foam was also to be used to repair 10 existing stoppings. Once constructed, the stoppings were to be tested for leaks, and evaluated and tested again after 6 and 12 month periods.

Unexpected program delays and higher-than-anticipated material and construction costs allowed for the completed construction of only 12 stoppings, and most of these were destroyed completely or partially before leak testing could be conducted. These in-mine problems prevented the completion of the total program. The program did, however, produce information of value on the utility of the final foam candidates as stopping sealants. In addition, performance as well as problems on new stopping construction techniques were evaluated.

DESCRIPTION OF TEST MINE

The in-mine tests were conducted in FMC's Trona mine at Green River, WY, during the period 7 to 16 June 1982. This mine is one of four Trona mines in the area, all of which have squeeze problems because of floor heaving. FMC and Texasgulf Chemical, an adjacent Trona mine, both are conducting in-house evaluations of stopping construction techniques to minimize the problem. FMC uses urethane foam as the final sealant on their stoppings and, therefore, had both basic equipment and personnel for the application of our foam candidates.

The FMC mine has conventional, continuous and longwall sections all in operation. Because of the blasting and subsequent squeeze, their greatest need for a flexible sealant is in the conventional sections. They are conducting their own, in-house stopping development efforts in these areas.

The mine uses a standard room and pillar panel development with entries and crossouts approximately 7 to 8 feet high by 15 to 18 feet wide. Their conventional stoppings for this area are constructed with wood blocks measuring 4" x 8" x 24". The blocks are laid up in a staggered joint pattern on a 2" x 8" plank footer and then wedged securely all around. Because of the blasting, the openings are rough and irregular requiring extensive fitting of blocks, and a large number of wedges to effect closure. A nominal 1" layer of polyurethane foam is sprayed on for the final seal.

Stoppings constructed of 8" x 12" x 42" polystyrene foam block, dry stacked to give both 8" and 12" thick walls, have been a more recent innovation. The joints were sealed with urethane foam. These, too, are

laid on a 2" x 8" or 2" x 12" plank footer and wedged. These stoppings lay up fast and are easily sealed. The materials handling and erection labor are significantly less than the block, but the materials themselves, are expensive.

FMC likes the polystyrene block stoppings even if costs are only comparable to the wooden block stoppings. The lightweight, larger pieces and easy fitting make for rapid construction.

Polystyrene foam stoppings blow out more readily than the wood stoppings during blasting. One or two pieces of lagging placed diagonally across the stoppings and sealed to the polystyrene with the urethane foam improve their stability.

PROPOSED TEST PROGRAM

MSAR proposed a program in which the foam candidates would be tested as the main air barrier on stoppings constructed on metal framing, using a coated brattice as the backing, and as a joint and perimeter seal for the polystyrene foam block stoppings. We believed that the new stopping design, using the light metal framework and coated brattice as a backing for a urethane foam stopping, would effect a significant improvement in materials handling labor over both the conventional wooden and the new polystyrene foam block stoppings. Stopping construction labor could be less than that for the wooden stoppings, but likely more than that for the polystyrene block. Material costs should be comparable.

Prior approval of the plan was obtained from local MSHA inspectors by the mine. The program outline was to install 10 stoppings using the metal framework and brattice cloth combination as backing, and 10 sealing the perimeter and joints of the polystyrene foam block stoppings. The two selected foams would be used on 5 of each type.

The test stoppings were to be placed about 10 feet in front of previously-placed wood block stoppings. This procedure insured ventilation, and allowed better scheduling during the construction of the test stoppings. Once the test stoppings were in place, the wood stoppings would then have a hole punched through them to expose the test stoppings to normal mine ventilation conditions. The enclosed volume between the two would later serve as an enclosed volume for leak testing with the Bureau's SF_6 leak test technique.

Metal Frame Stopping Design

The metal frame backed stopping design was patterned after work being conducted by Ned Miles at U.S. Steel for their coal mines, in which squeezing is also a problem. In this approach, Miles used a prefabricated framework of galvanized steel channel to support expanded metal lath. The vertical supports were built in two sections that telescope within one-another to accommodate variable mine heights. A cement-based sealant trowelled to the lath formed the final air seal.

Our approach employed smaller metal frame members and jute-backed brattice cloth, vinyl coated one side to support the sprayed urethane foam sealant. The frame was constructed of 1-5/8" track and frame members of 20 gauge galvanized steel from Bostwick Steel Lath Company, Niles, OH. The components and assembly technique are shown in Figure 8.

The erection technique consisted of the pre-assembly of 8' sections of the metal framework without those telescoping stud sections that would overlap at the center. The telescoping stud sections were fastened to the top and bottom track on 18" centers by punching a tap hole in the jointing members using a modified vise-grip tool, and installing hex-head, self-tapping screws. The section was then erected in the opening and the top and sides fastened to the rock roof and ribs. After all sections were in place, the bottom track was forced to the floor and nailed with 30 or 40 D spikes and a hose clamp securely fastened around the overlapping sections of the metal studs.

Fastening the track to roof and ribs was done with pop rivets. Initially, rivets were installed by drilling a hole with a small hand drill to about a 3/4 inch depth. The task was laborious. Later, power was tapped off of the battery-powered jeeps to do the job.

The brattice was installed by overlapping and prefastening extra long 6 ft. wide strips to the top track with the self tapping screws, and pulling it tight under the base before fastening the base to the mine floor. The strips were overlapped several inches on the edges on a stud, and the lapped edges wired tightly to the backing stud at several places. Sequential photos of a stopping erection in the mine is shown in Figures 9 and 10.

The vinyl-coated burlap brattice was installed with the burlap exposed to the fresh air entry, with the studs behind. The burlap provided the rough surface for the urethane foam. It was later suggested that a more rigid seal might be made by fastening the brattice with the studding in front so that the subsequent foaming process would envelope the studding and fasten each to the brattice over its entire length.

Polystyrene Foam Block Stoppings

Polystyrene foam block stoppings were used by FMC to construct permanent stoppings. MSAR's plan was to test the two foam candidates as joint and perimeter sealants by spraying the foam directly on the polystyrene.

In the course of our work, however, we made one contribution to the company's design that appeared to be a definite improvement in providing additional strength against blast shockwaves. It was the mine's practice to place one or two 2" x 8" lagging members across the face of the stopping and seal them to the foam with the subsequent foam application. While helping rebuild one such large stopping that had been blown out, MSAR personnel suggested installing a parallel lagging

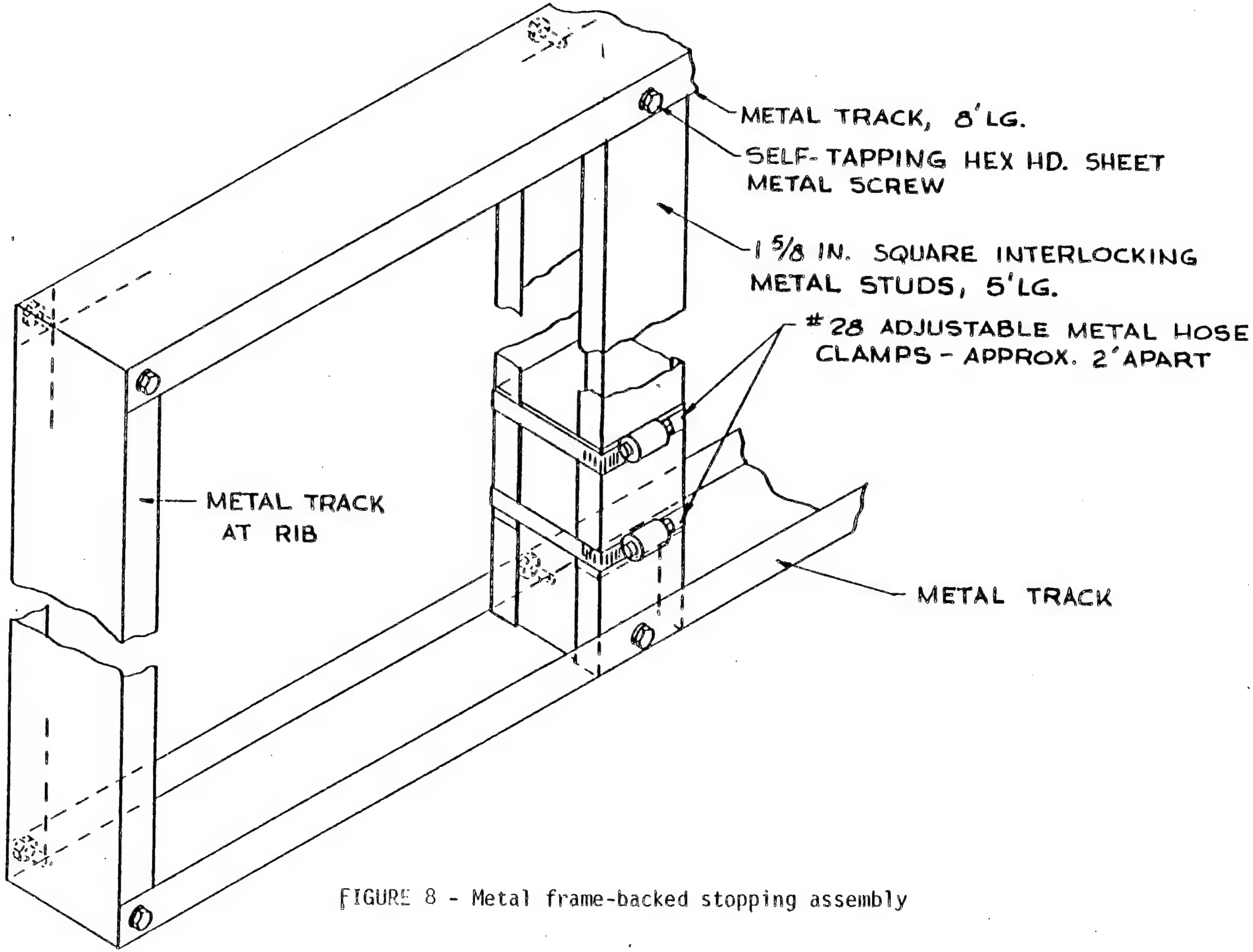


FIGURE 8 - Metal frame-backed stopping assembly

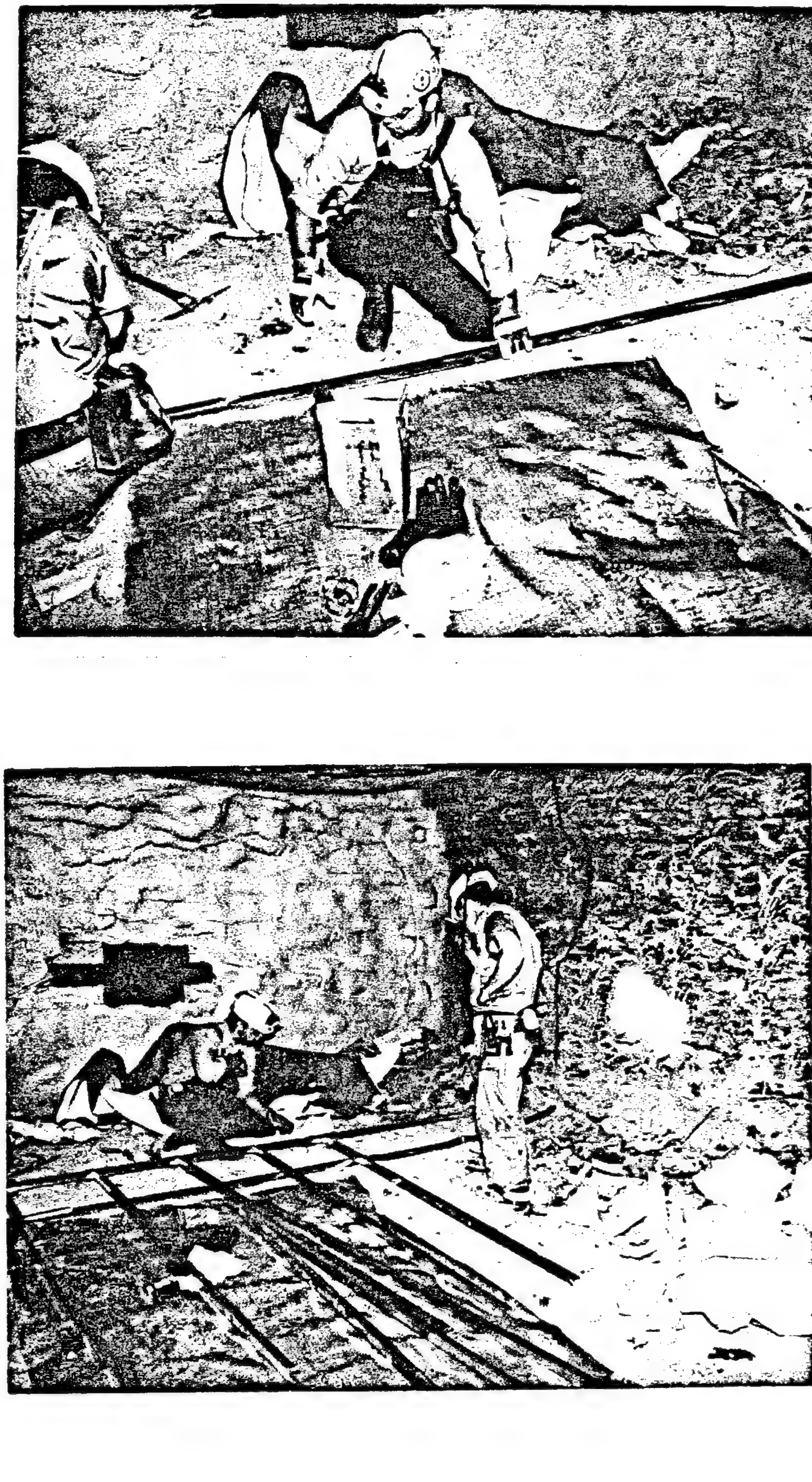
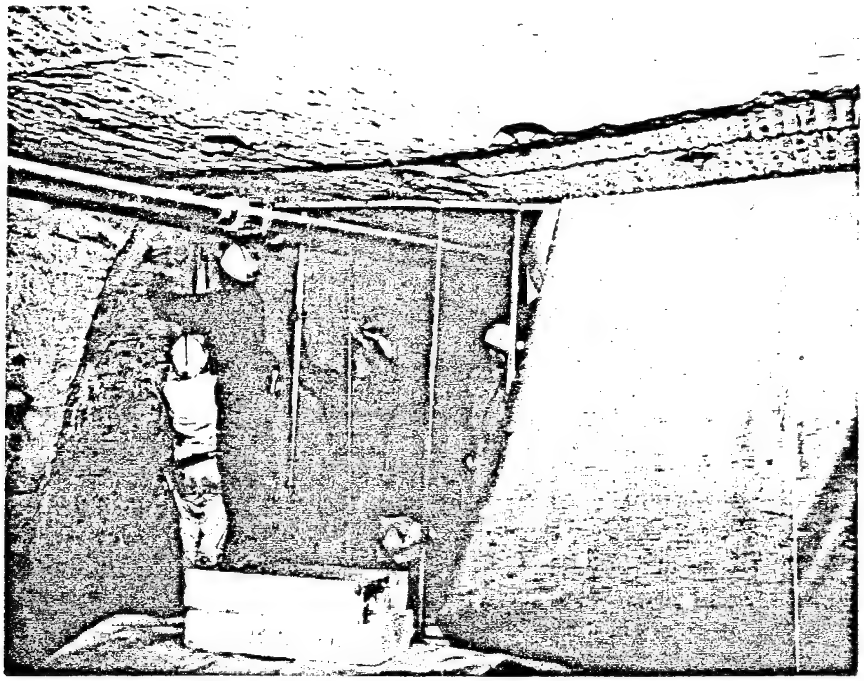


FIGURE 9 - Metal frame-backed stoppings under construction



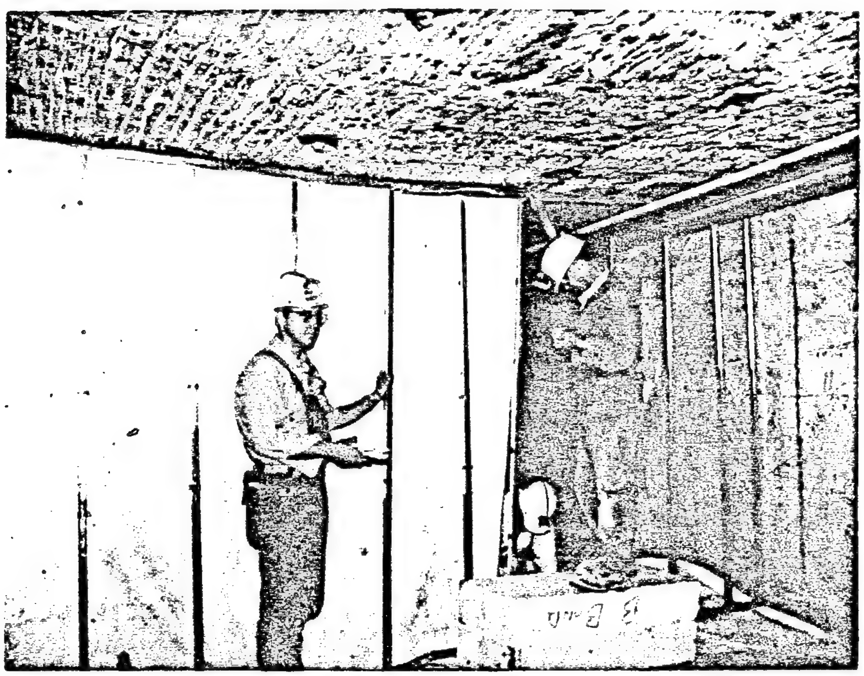


FIGURE 10 - Metal frame-backed stoppings under construction

member on the back side of the stopping and binding the two together tightly with wires.

The binding wires were easily pushed through the polystyrene block stoppings, and when twisted tight with a wood or metal member, sandwiched the foam blocks tightly between the lagging. The urethane foam was applied on the surface as before. This technique would tend to distribute any potentially rupturing force more evenly over the full face of the stopping.

TEST SUMMARY

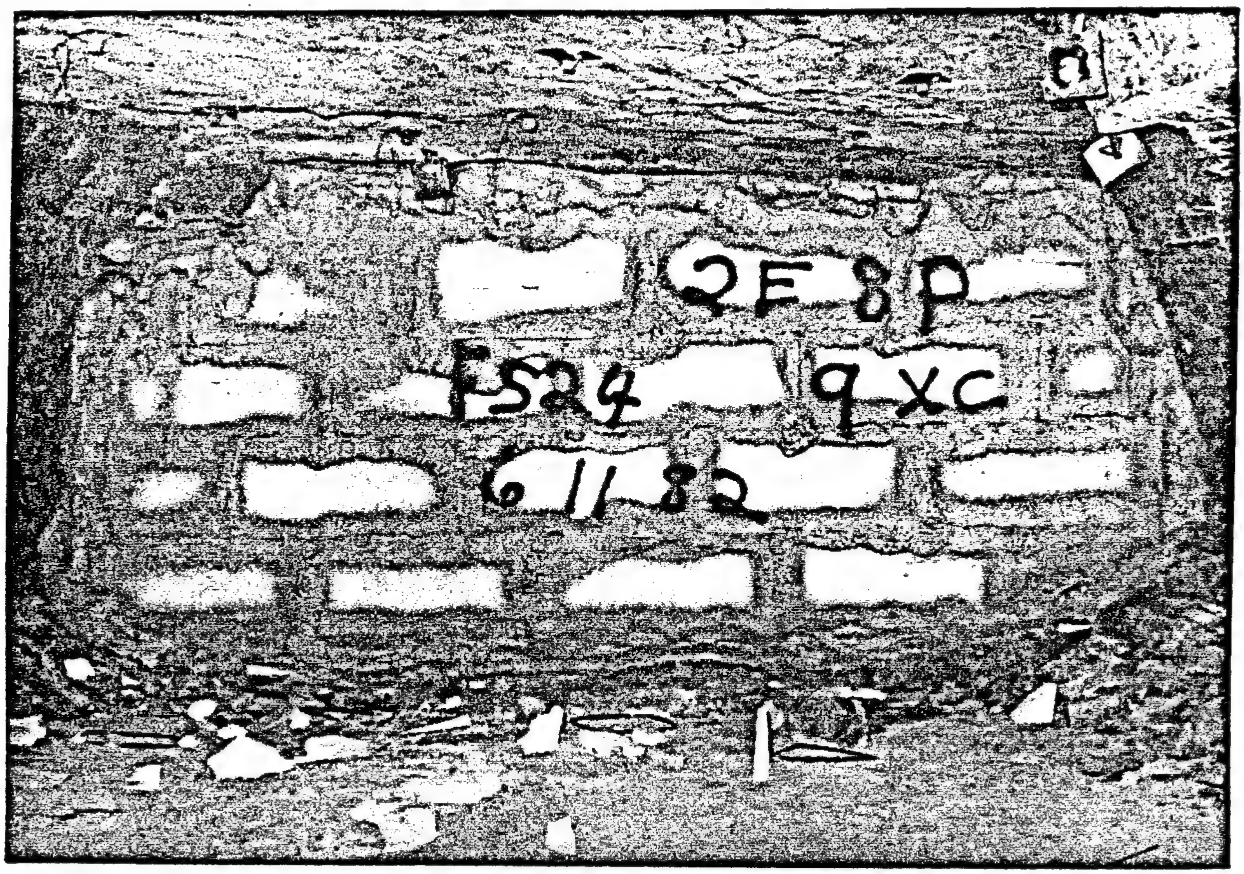
A summary of the test stopping construction is shown in Table 51. The stopping sizes were nominal 8' H x 16' W, with variances running to 10' high and 19' wide. The problems involved and status approximately one month after installation are included in the comments. A summary of the test follows:

The test program called for the installation of 10 metal frame stoppings and 10 in which urethane was the sealant on new polystyrene foam block stoppings. The 10 foam block test stoppings were installed. However, severe shock waves set up by either exceptionally heavy charges or improper timing sequences during production blasting caused considerable damage not only to the test stoppings, but to the mine's normal wooden and polystyrene stoppings. In one case, the first day's construction effort, consisting of 2 each of the foam block and metal-backed stoppings placed alternately, were destroyed overnight. Two of those destroyed were in the 6th and 7th crosscuts from the face, demonstrating the extreme force of the shock waves. The foam stoppings were salvable. The metal stoppings were completely demolished.

This pattern was repeated with later test efforts. In another panel, two foam block stoppings placed in crosscuts 5 and 6 back from the face were blown out after being foamed. Subsequent test stoppings, placed 16 and 20 cross cuts from the face, also suffered blast damage. This damage was unusually severe, according to the mine ventilation personnel. These problems severely hampered our efforts. Before and after photos of both types of stoppings are shown in Figures 11 and 12. Because of the heavy blast over-pressures, only two metal/brattice stoppings were able to be completed in the time allotted.

TABLE 51 - Summary of test stopping program at FMC mine, Green River, WY

Stopping no.	Type	Foam identification	Comments
8 Panel - Face at Crosscut 30			
26	Foam block	X-156	Installed completely; blast damage showing 8 sq. ft. missing and perimeter cracking
25	"	X-156	Installed completely; blast damage bowed and cracked perimeter.
15	"	X-156	Installed completely; blast damage showed cracks on perimeter
12	"	X-156	Installed completely; intact
11	"	X-156	Installed completely; intact
9	"	FS-24	Installed completely; intact
7	"	FS-24	Installed completely; intact
5	"	FS-24	Installed completely; intact
10 Panel - Face at Crosscut 7			
2	Foam block	FS-24	Blown out before foaming; repaired and sprayed; intact
1	Metal frame	FS-24	Blown out before foaming; repaired and blown out 2nd time; removed
Haulage 2	Foam block	--	Blown out before foaming; repaired and sprayed; intact
Haulage 1	Metal frame	FS-24	Buckled during blasting; repaired and sprayed; blown out subsequently



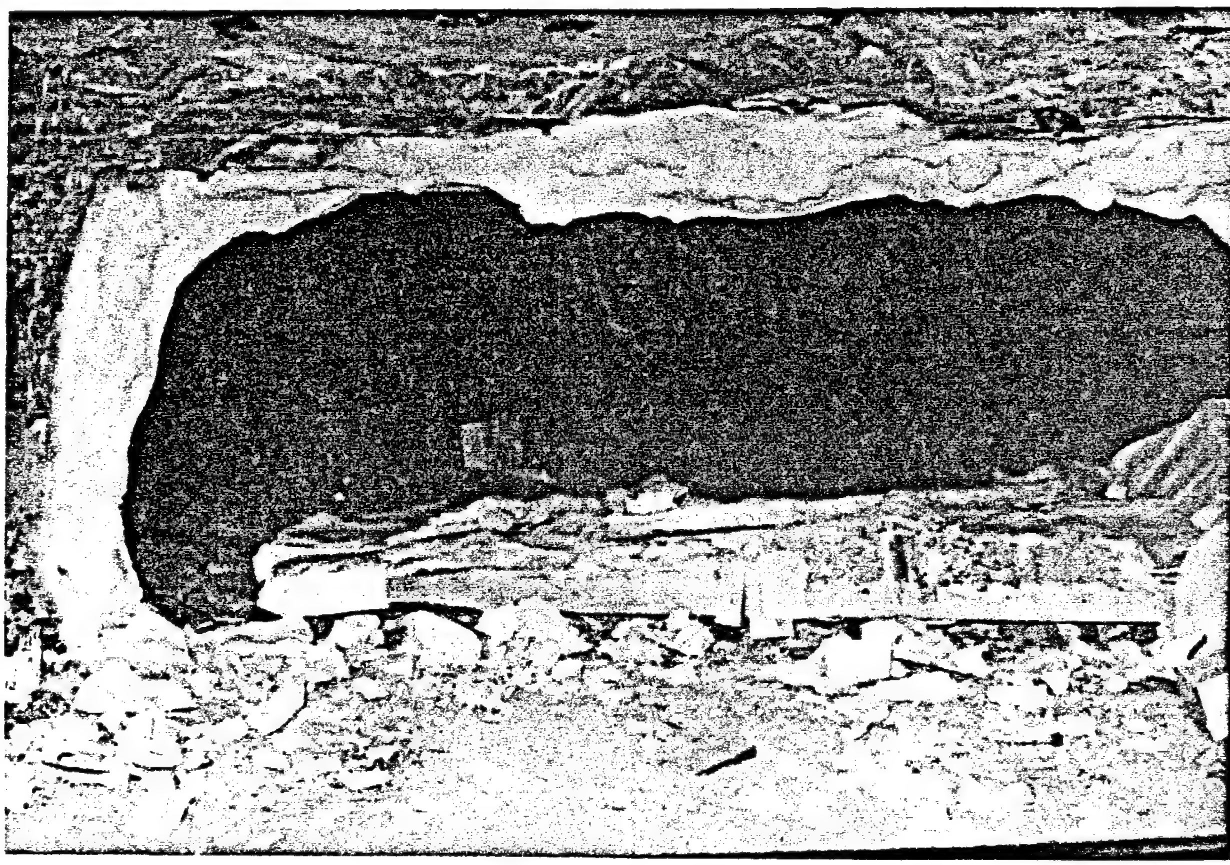
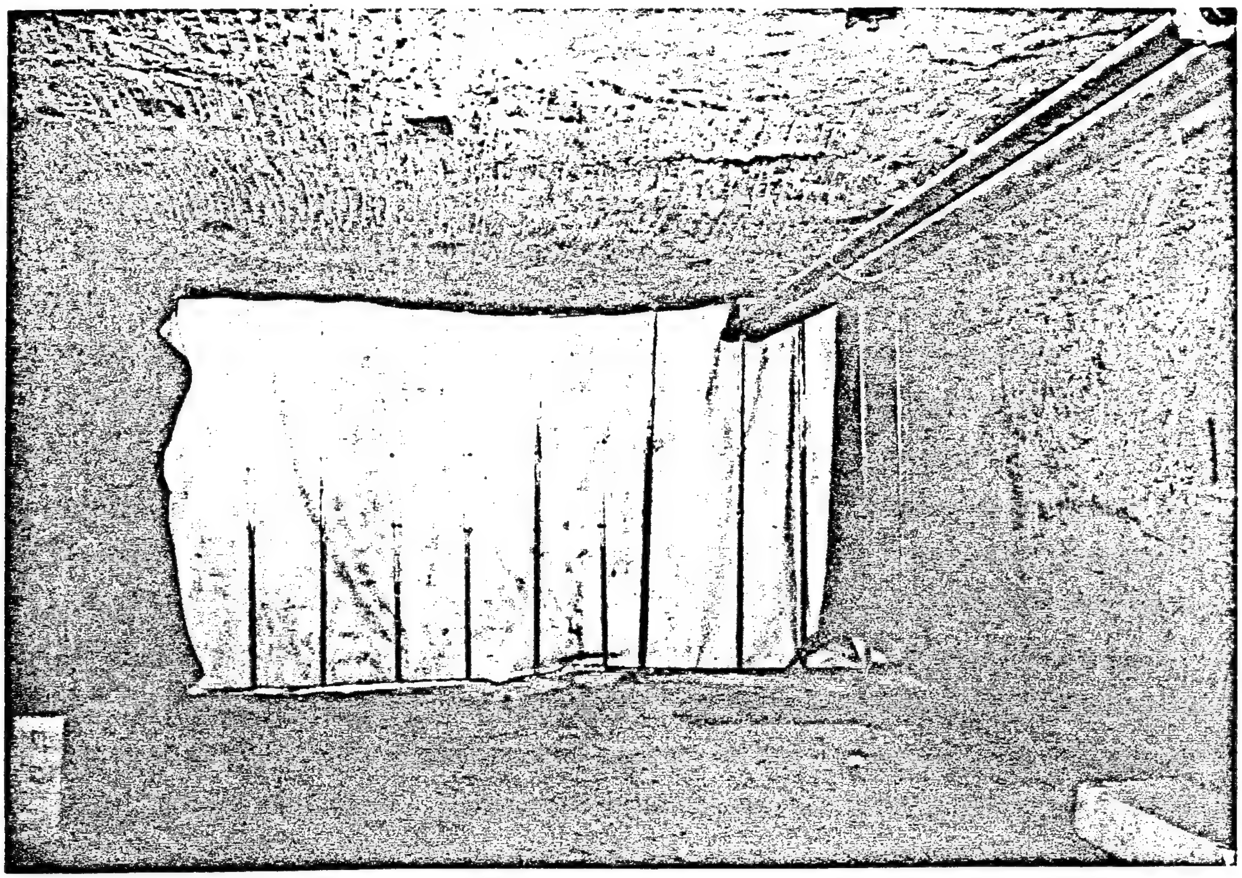


FIGURE 11 - Before and after photos of polystyrene block stoppings showing effects of blasting



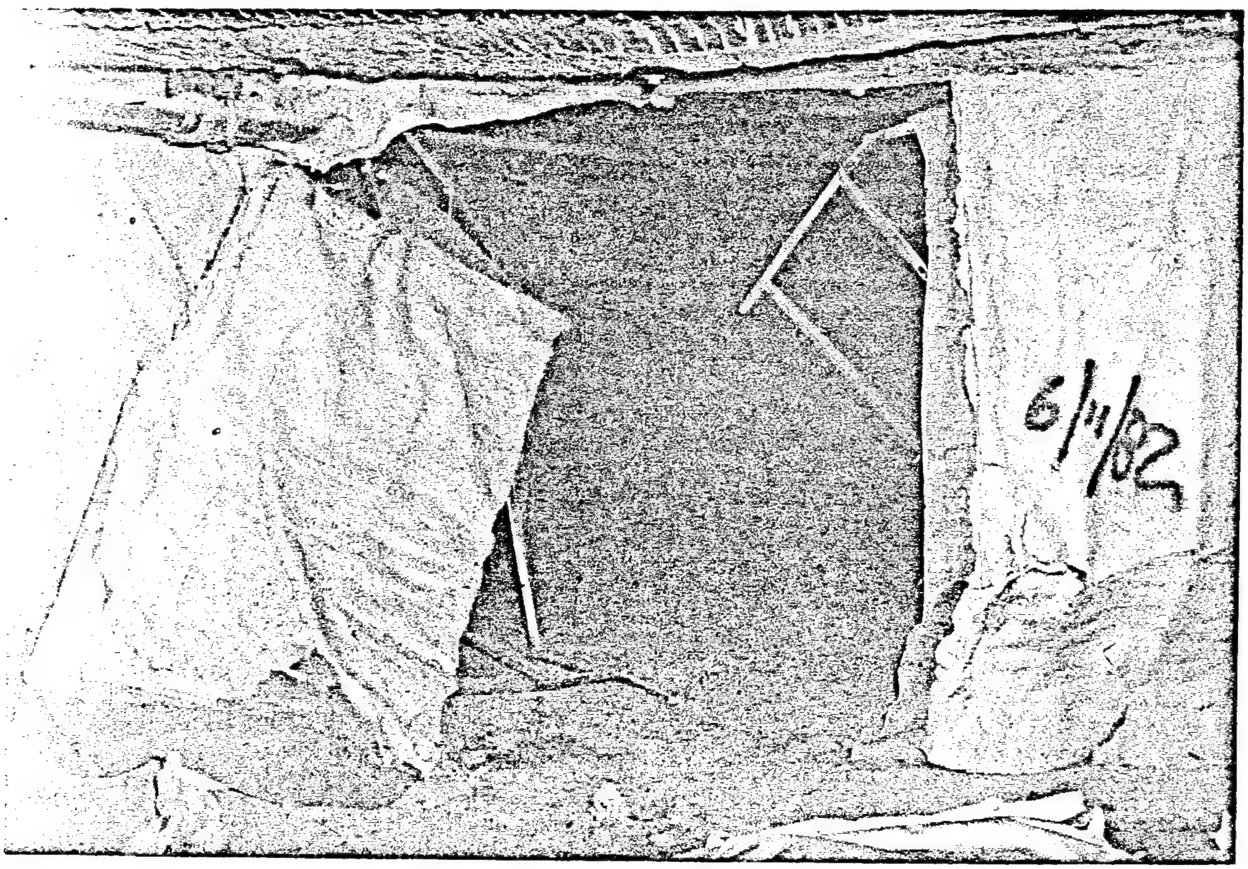


FIGURE 12 - Before and after photos of metal frame-backed stoppings showing effects of blasting

SUMMARY

A total of 27 foams representing 5 generic types of foam were selected from an industry-wide survey and evaluated for use as a sealant for mine stoppings.

Flame spread data, used in the evaluations of this program, were obtained by ASTM-E162 tests and a modification, signified as E162-CCC-2. These data differed significantly from manufacturer's published results of the ASTM-E84, 25 ft. tunnel test. No adequate correlations of these data became apparent during this investigation.

The general quality and fire-resistance of rigid foams have improved considerably over the years. The best of the earliest candidates entering the market is now about equal to the average product performance in these two areas.

Ten to fifteen of representative foam materials selected for evaluation were considered to have generally "good" properties. Three of these had "outstanding" flame spread indices and three others were considered "good". However, two that were "outstanding" had high air permeability and were thus unsuitable for stoppings.

The best foam clearly was Item 5, X-156, offered by Callery Chemical Company/Mine Safety Appliances Company. It ranked at the top by flame spread testing and equivalent in all of the remaining tests, except adhesion to wet surfaces.

The second foam, initially selected was Item 15, Olin Chemical's Poly System 7622-02. It was grouped closely with foam candidates from the Freeman and Witco Chemical Companies, either of which could just as well have been selected.

The unavailability of a polyol used in the formulation of these leading candidates, however, caused all of them to be dropped from consideration. Because of insufficient market potential, Olin Corporation, the supplier of Thermolin RF230, decided to stop production.

Foam System's FS-24 (Item 11), was selected as the replacement for Olin's Poly System 7622-02. Although lower ranked than the bypassed candidates by E162, it had excellent adhesion test data.

In-mine test of the "final 2" candidate foams were conducted in FMC's Trona mine at Green River, Wyoming, in a conventional mining section subjected to squeeze conditions. The foams were employed as joint and perimeter seals for polystyrene foam block stoppings under test by FMC, and as a face sealant for a light metal framework/brattice stopping.

The metal framework/brattice combination as backing for the urethane foam sealant proved to be unsuitable for the conventional mining section. The openings were too irregular to allow for convenient erection and the type construction ultimately too flimsy to withstand the blasting shockwaves. Attempts to install this type even at considerable distances from the face were soon abandoned because of the problems of erection in the rough openings. We feel, however, that this design would be suitable for continuous miner sections where the openings are more regular and blasting nonexistent.

Both the X-156 and FS-24 foams applied readily with the foam applicator equipment. Subsequent shockwaves proved the FS-24, however, to be superior to X-156 in adhesion to foam, wood and stone surfaces. The more brittle X-156 cracked under load and released significantly from the substrates. This was particularly noticeable on the polystyrene foam where, if failure occurred, with X-156 a urethane/foam substrate break occurred, whereas with FS-24 the break occurred in the polystyrene.

Although an indictment against X-156, these results should be reviewed in context. X-156 demonstrates that foams far superior to FS-24 on flame properties are possible, but may have to trade off other properties (such as adhesion) to achieve the high flame resistance. Under less extreme circumstances, however, where disruptive blasting shockwaves are not present, the adhesion of such foams may prove to be more than adequate.

APPENDIX

Table A-1 is a detailed listing of Manufacturers contacted during our survey for foamed materials candidates in Phase I of the program. Table A-2 is a listing of the foams that resulted from the survey, their properties as obtained from the manufacturer or published literature, and our assessment as to their suitability for mine use. A code sheet and comments on property designations are included to assist in the interpretation of the table.

TABLE A-1 - Manufacturers contacted in survey of foamed materials

Generic foam type	Company
ABS	Borg-Warner Corporation Borg-Warner Chemicals & Plastics International Center Parkersburg, WV 26101
Acetal	Celanese Plastic Materials Co. 26 Main Street Chatham, NJ 07925
Cellulose acetate	American Polymers, Inc. 50 California Avenue Paterson, NJ 07503
	Deltex Associates 122 Lowell Street Carterette, NJ 07008
	Eastman Chemical Products, Inc. P.O. Box 331 Kingsport, TN 37662
Epoxy	Bacon Industries, Inc. 192 Pleasant Street Watertown, MA 02172
	Isochem Resins Company Cook Street Lincoln, RI 02865
	Shell Chemical Company One Shell Plaza Houston, TX 77002
	Sika Chemical Company 631 Idlewood Avenue Carnegie, PA 15106
Epoxy (cont)	Emerson and Cumings, Inc. 869 Washington Street Canton, MA 02021
	Ren Plastics 5656 South Cedar Street Lansing, MI 48909
	Kristal Kraft, Inc. P.O. Box 787 Palmetto, FL 33561
Ionomer	Gilman Brothers Company 102 Main Street Gilman, CT 06336
Isocyanurate	Chemetics Systems, Inc. 2006 Gladwick Street Compton, CA 90220
	Texas Urethanes 10137 Highway 290 East Austin, TX 78766
	Foam Systems Company 3640 Chicago Avenue Riverside, CA 92507
	Upjohn Company, CPR Division 555 Alaska Avenue Torrance, CA 90503
Melamine-based	American Cyanamid Chemical Research Division 1937 West Main Street Stamford, CT 06904

TABLE A-1 - Manufacturers contacted in survey of foamed materials (cont)

Generic foam type	Company
Phenolic	Schenectady Chemicals, Inc. P.O. Box 1046 Schenectady, NY 12301
	Smithers Company Oasis Division 919 Marvin Avenue Kent. OH 44240
Phenylene oxide-based	General Electric Company Plastics Division One Plastics Avenue Pittsfield, MA 01201
Polyamide-imide	Amoco Chemicals Corporation 200 East Randolf Street Chicago, IL 60601
	Enplax Corporation P.O. Box 22 234 Franklin Avenue Nutley, NJ 07110
	Allied Chemical Corporation Fibers and Plastics Company P.O. Box 2332R Morristown, NJ 07960
	Celanese Plastic Materials Co. 26 Main Street Chatham, NJ 07928
Polybenzimidazole	Armstrong Cork Company 1010 Concord Street Lancaster, PA 17603

Generic foam type	Company
Polycarbonate	General Electric Company Engineering Structural Foam Resins Plastics Division One Plastics Avenue Pittsfield, MA 01201
Polyethylene	Dow Chemical Company 2020 Dow Center Midland, MI 48640
	Dynamit Nobel of America, Inc. 105 Stonehurst Ct. Northvale, NJ 07647
	Vantage Products Conyers, GA 30207
	Crest Foam, Inc. 100 Carol Place Moonachie, NJ 07075
	Northern Petrochemical Co. Nortech Division 830 Main Street Clinton, MA 01510
	Rogers Foam Corporation 20 Vernon Street Somerville, MA 02145
	United Minerals and Chemicals Corp. 129 Hudson Street New York, NY 10013

TABLE A-1 - Manufacturers contacted in survey of foamed materials (cont)

Generic foam type	Company
Polyimide	Ciba-Geigy Corporation SPE Aerolite Division 8025 Dixie Highway Florence, KY 41042
	Monsanto Company 800 N. Linbergh Boulevard St. Louis, MO 63166
Polypropylene	Northern Petrochemical Co. Nortech Division 830 Main Street Clinton, MA 01510
	Vantage Products Conyers, GA 30207
	Sun Chemical Corporation Facile Division 185 Sixth Avenue Paterson, NJ 07524
Polystyrene	Dow Chemical Company 202 Dow Center Midland, MI 48640
	Northern Petrochemical Co. Nortech Division 830 Main Street Clinton, MA 01510
Polyurethane	Atlas Minerals and Chemicals Farmington Road Merztown, PA 19539

Generic foam type	Company
Polyurethane (cont)	Chemetics Systems, Inc. 2006 Gladwick Street Compton, CA 90220
	Fomo Products, Inc. 1090 Jacoby Road Akron, OH 44321
	Furane Plastics, Inc. 5121 San Fernando Road Los Angeles, CA 90039
	BASF Wyandotte Corporation Wyandotte, MI 48192
	Cook Paint & Varnish Company P.O. Box 389 Kansas City, MO 64141
	Freeman Chemical Corporation P.O. Box 247 Port Washington, WI 53074
	Hastings Plastics Company 1704 Colorado Avenue Santa Monica, CA 90404
	Insta-Foam Products, Inc. 2050 N. Broadway Joliet, IL 60435
	Lankro Chemicals, Ltd. P.O. Box 1 Eccles, Manchester England M30 OBH

TABLE A-1 - Manufacturers contacted in survey of foamed materials (cont)

Generic foam type	Company
Polyurethane (cont)	Kristal Kraft, Inc. P.O. Box 787 Palmetto, FL 33561
	M-R Plastics and Coatings 11460 Dorsett Road Maryland Heights, MO 63043
	Magnolia Plastics, Inc. 5547 Peachtree Ind. Pk. Blvd. Chamble, GA 30341
	Midwest Manufacturing Corp. Oak Street at Bluff Road Burlington, IA 52601
	Olin Chemical Corporation 120 Long Ridge Road Stamford, CT 06904
	Pelron 7847 West 47th Street Lyons, IL 60534
	Fremont-Hayward California
	Reichold Chemicals, Inc. 525 North Broadway White Plains, NY 10603
	Stepan Chemical Company Urethane Department Northfield, IL 48106

Generic foam type	Company
Polyurethane (cont)	Hoover Universal Chemical Specialties Division P.O. Box 1424 Ann Arbor, MI 48106
	Texas Urethanes 10137 Highway 290 East Austin, TX 78766
	United Foam Corporation 2626 Vista Industria Compton, CA 90221
	Upjohn Company, CPR Division 555 Alaska Drive Torrance, CA 90503
	Urethane Systems Corporation 109 West 134th Street Los Angeles, CA 90061
	Utah Foam Products 572 South 2165 West Salt Lake City, UT 84104
	Witco Chemical Company Isocyanate Products Division 900 Wilmington Road New Castle, DE 19720
	Ashland Chemical Company P.O. Box 2219 Columbus, OH 43216
	W. R. Grace and Company Chemical Foam Systems Columbia, MD 21044

TABLE A-1 - Manufacturers contacted in survey of foamed materials (cont)

Generic foam type	Company
Polyurethane (cont)	Firestone Corporation Urethane Foam Division Foam Products Company 823 Waterman Avenue, Box 4159 East Providence, RI 02914
	Owens-Corning Company Fiberglass Tower Toledo, OH 43659
	Tenneco Chemicals Foam Division Valmont Industrial Park West Hazelton, PA 18201
	Mobay Chemical Company Parkway West Pittsburgh, PA 15235
	Cargill, Inc. 15407 McGinty Road Minneapolis, MN
	Essex Chemical Corporation 1-T Crossman Road, S Sayreville, NJ 08872
	Callery Chemical Company Evans City, PA 16033
PVC	Diamond Shamrock Corporation 1110 Superior Avenue Cleveland, OH 44114

Generic foam type	Company
PVC (cont)	Tenneco Chemicals Foam Division Valmont Industrial Avenue West Hazelton, PA 18201
	Firestone Plastics Company P.O. Box 699 Pottstown, PA 19464
	Colorite Plastics Company 101 Railroad Avenue Ridgefield, NJ 07657
Silicate	Diamond Shamrock Company Technical Center Box 191 Painesville, OH 44077
	Caledonia Mining Company, Ltd. Carlton-on-Trent (Newark) Nottinghamshire England NG236NT
	Southwest Research Institute 6220 Culebra San Antonia, TX 78228
	Fiberglass Canada, Ltd. Box 3005 Sarnia, Ontario Canada N7T7M6
Silicone	Dow-Corning Corporation P.O. Box 1767 Midland, MI 48640

TABLE A-1 - Manufacturers contacted in survey of foamed materials (cont)

Generic foam type	Company
Silicone	General Electric Company Silicone Products Department Mechanicville Road Waterford, NY 12188
	Emerson and Cuming, Inc. 869 Washington Street Canton, MA 02021
Thermoplastic polyester	General Electric Company Plastics Division One Plastics Avenue Pittsfield, MA 01201
	Celanese Plastic Material Co. 26 Main Street Chatham, NJ 07928
	Owens-Corning Fiberglass Corp. Fiberglass Tower Toledo, OH 43659
Urea-formaldehyde	Arrowhead Plastics Engineering, Inc. P.O. Box 412 Muncie, IN 47305
	Ciba-Geigy Corporation Plastics Division Saw Mill River Boulevard Ardsley, NY 10502
	Borden, Inc. 180 E. Broad Street Columbus, OH 43215
Urea-formaldehyde (cont)	Rapco, Inc. 518 South Eleventh Street Richmond, CA 94804

Also, for a natural rubber blended material which is sprayable:

Generic foam type	Company
	H. L. Blackford, Ltd. 2323 Royal Windsor Drive Mississauga, Ontario Canada L5J1K5

TABLE A-2 - Properties of foams surveyed

Generic type	ABS	Acetal	Amide/Imide		Epoxy	Ionomer	Nitrile/vinyl
Supplier	Borg-Warner Corporation	Celanese Plastics Co.	Allied Chemical	Celanese Plastics Co.	Ren Plastics	Gilman Brothers	Armstrong Cork
Product identity	Cycolac FBK	Celcon M90	Capron XPN 1173	Nylon 1503	RP 1774	Surlyn Softlite	Armaflex II
Type of foam	Rigid	Rigid	Rigid	Rigid	Rigid	Semi-rigid	Flexible
Density, lb/ft^3	45	62	55	60	15	3	6
Comp strength, psi*	3000	ND	ND	ND	450	2	3
Tensile strength, psi*	2000	5400	9000	13,400	ND	100	ND
Combustibility, rating*	V0/5V	HB	(14)	HB	(14)	Pass	25
, method	UL94	UL94	ND	UL94	ND	M.V. 302	E84
, smoke	ND	ND	ND	ND	ND	ND	100/150
Water absorption, lbs/ft^2*	ND	ND	ND	ND	ND	ND	ND
, %	0.3	ND	1.6	ND	ND	0.1	6
Moisture vapor transmission,* perm in	ND	ND	ND	ND	ND	ND	0.17
Maximum service temp, °F*	170	307	300	490	128	160	220
Commercial use*	(1)	(1)	(1)	(1)	(1)	(2)	(4)
Mode of preparation*	(5)	(5)	(5)	(5)	Pour	(5)	(5)
Equipment costs, $1000	50-250	50-250	50-250	50-250	10	50-250	None
Stopping cost/100 ft^2, $	115	185	185	185	115	45	115
at thickness, in	0.25	0.25	0.25	0.25	0.5	1.0	0.25
Unusual positive properties*	(6)	(6)	(6)	(6)	None	None	None
Unusual negative properties*	(13)	(13,14)	(13,14)	(13,14)	(14,20)	(13,14)	(13)
Suitable for mine use?	No	No	No	No	No	No	Maybe
As to mode of production?	No	No	No	No	Maybe	No	Maybe
As to combustibility?	Maybe	No	No	No	No	No	Yes

*Refer to code sheet at end of table

TABLE A-2 - Properties of foams surveyed (cont)

Generic type	Phenol/formaldehyde		Phenylene Oxide	Polycarbonate	Polyethylene	Urea/formaldehyde	
Supplier	Reichhold Ltd.	Schenectady Chemicals	General Electric	General Electric	Dow Chemical	Ciba-Geigy	Raperswill
Product identity	Phenolite 1B322/1D644	HRJ-913	Noryl FN215	Lexan 1800	Ethafoam 222	Aerolite SPE	Rapco-Foam
Type of foam	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid
Density, lb/ft^3	3	3	50	60	3	1	0.7
Comp strength, psi*	20	ND	ND	ND	6 - 12	1.5	ND
Tensile strength, psi*	ND	ND	3600	6300	100	ND	ND
Combustibility, rating*	5	(14)	110	18	Burning	20	25
, method	E84	ND	E162	E162	ND	E84	E84
, smoke	0	ND	ND	ND	ND	125-200	0 - 5
Water absorption, lbs/ft^2*	ND	ND	ND	ND	ND	ND	ND
, %	25	ND	0.07	ND	0.2	15	2.2
Moisture vapor transmission,* perm in	ND	ND	ND	ND	0.3	20	35
Maximum service temp, °F*	400	ND	180	270	180	200	ND
Commercial use*	(4)	(4)	(1)	(1)	(2,4)	(4)	(4)
Mode of preparation*	Pour/Spray	Pour	(5)	(5)	(5)	Pour/Spray	Pour/Spray
Equipment costs, $1000	10	10	50-250	50-250	None	6	6
Stopping cost/100 ft^2, $	45	45	115	185	45	45	45
at thickness, in	1.0	1.0	0.25	0.25	1.0	1.0	1.0
Unusual positive properties*	(10,11)	None	(6)	(6)	None	None	(11)
Unusual negative properties*	(15,18)	(14,18)	(13,14)	(13)	(13,14)	(15,17)	(15,17,22,23)
Suitable for mine use?	Maybe	No	No	No	No	Maybe	Maybe
As to mode of production?	Yes	No	No	No	No	Yes	Yes
As to combustibility?	Yes	No	No	Yes	No	Yes	Yes

*Refer to code sheet at end of table

TABLE A-2 - Properties of foams surveyed (cont)

Generic type	Silicones					Thermoplastic polyesthers		
Supplier	Dow-Corning	Emerson & Cuming	General Electric	General Electric	General Electric	Celanese Plastics Co.	Celanese Plastics Co.	General Electric
Product identity	3-6548RTV	Eccofoam SIL	RTV 6428	RTV 7403	RTV 850	Celanex 3210	Celanex 3310	Valox FV-600
Type of foam	Flexible	Flexible	Flexible	Elastomer	Semi-rigid	Rigid	Rigid	Rigid
Density, lb/ft^3	17	20	85	80	20 - 25	68	72	70
Comp strength, psi*	5	5	ND	ND	ND	ND	ND	ND
Tensile strength, psi*	33	100	400	25	ND	9000	10,200	7000
Combustibility, rating*	20	(14)	13	25	21	VO	VO	VO
, method	E84	ND	E84	E84	UL94	UL94	UL94	
, smoke	ND	ND	54	ND	204	ND	ND	ND
Water absorption, lbs/ft^2*	ND	ND	ND	ND	ND	ND	ND	ND
, %	ND	0.1	ND	ND	ND	ND	ND	0.26
Moisture vapor transmission,* perm in	ND	ND	ND	ND	ND	ND	ND	ND
Maximum service temp, °F*	High	400	High	High	High	417	424	340
Commercial use*	(3)	(3)	(3)	(3)	(3)	(1)	(1)	(1)
Mode of preparation*	Pour	Pour	Pour	Pour	Pour	(5)	(5)	(5)
Equipment costs, $1000	10	6-10	10+	10+	10+	50-250	50-250	50-250
Stopping cost/100 ft^2, $	485	485	485	485	485	185	185	185
at thickness, in	0.5	0.5	0.15	0.15	0.5	0.25	0.25	0.25
Unusual positive properties*	(9)	(9)	(9)	(9)	(9)	(6,9)	(6,9)	(6)
Unusual negative properties*	(16,20)	(14,16,20)	(16,20)	(16,20)	(16,20)	(13)	(13)	(13)
Suitable for mine use?	Maybe	No	Maybe	Maybe	Maybe	No	No	No
As to mode of production?	Maybe	Maybe	Maybe	Maybe	Maybe	No	No	No
As to combustibility?	Yes	No	Yes	Yes	Yes	Maybe	Maybe	Maybe

*Refer to code sheet at end of table

TABLE A-2 - Properties of foams surveyed (cont)

Generic type	Isocyanurates					Urethanes		
Supplier	Chemetics Systems	Foam Systems	Insta-Foam Products	Texas Urethanes	Upjohn Co.	Ashland Chemical	Atlas Minerals and Chemicals	
Product identity	CSI 9575	FSC 55	ICU Kit	Texthane 333	Isonate CPR425	Phenolic Urethane	Urefoam R-02	Urefoam R-07
Type of foam	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid
Density, lb/ft^3	2.5	2	2.5	2.1	2	2	2	7
Comp strength, psi*	40	30	20	27	26	35	5	80
Tensile strength, psi*	75	45	40	ND	50	ND	13	65
Combustibility, rating*	25	25	25	25	25	20	ND	ND
, method	E84	E84	E84	E84	E84	E84	ND	ND
, smoke	150	250-450	400	ND	400	140	ND	ND
Water absorption, lbs/ft^2*	ND	ND	ND	ND	ND	ND	ND	ND
, %	ND	ND	3	ND	ND	ND	0.11	0.05
Moisture vapor transmission,* perm in	ND	ND	3	ND	2.5	ND	ND	ND
Maximum service temp, °F*	ND	ND	300	ND	ND	225	170	170
Commercial use*	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)
Mode of preparation*	Spray	Spray	Froth	Froth	Spray	Pour	Pour	Pour
Equipment costs, $1000	6	6	None	10	6	6	6	6
Stopping cost/100 ft^2, $	45	45	300	45	45	60	45	90
at thickness, in	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Unusual positive properties*	None	None	None	None	None	None	None	None
Unusual negative properties*	(22)	(21)	None	(22,23)	(22,23)	None	(14,15)	(14)
Suitable for mine use?	Yes	No	Yes	Yes	Yes	Yes	No	No
As to mode of production?	Yes	Yes	Yes	Yes	Yes	Maybe	No	No
As to combustibility?	Yes	Yes	Yes	Yes	Yes	Yes	No	No

*Refer to code sheet at end of table

TABLE A-2 - Properties of foams surveyed (cont)

Generic type	Urethanes							
Supplier	BASF Wyandotte	CCC/MSA	CCC/MSA	Chemetics Systems	Chemetics Systems	Chemetics Systems	Cook Paint and Varnish Co.	
Product identity	Pluragard S-602	Rigimix E/F	X-156	CSI 8420	CSI 9120	CSI 9152	Coro-Foam G 325	Coro-Foam 440
Type of foam	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid
Density, lb/ft^3	2	2	2	2	2	2	2	2
Comp strength, psi*	30	30	30	33	29	35	27	25
Tensile strength, psi*	40	40	40	38	27	40	ND	ND
Combustibility, rating*	25	25	20	20	20	20	30	25
, method	E84	E84	E84	E84	E84	E84	E84	E84
, smoke	350	350	150	190	110	305	185	75
Water absorption, lbs/ft^2*	ND	ND	ND	ND	ND	ND	ND	ND
, %	ND	ND	ND	0.1	0.03	0.03	0.06	0.06
Moisture vapor transmission,* perm in	ND	2.5	2.5	2	2	2	2.5	2.5
Maximum service temp, °F*	250	250	250	ND	ND	ND	ND	ND
Commercial use*	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)
Mode of preparation*	Spray	Spray	Spray	Froth	Spray	Spray	Spray	Froth
Equipment costs, $1000	6	6	6	10	6	6	6	10
Stopping cost/100 ft^2, $	45	45	45	45	45	45	45	45
at thickness, in	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Unusual positive properties*	None	None	(11)	None	(11)	None	None	(11)
Unusual negative properties*	(22)	None	None	None	(22)	None	None	None
Suitable for mine use?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
As to mode of production?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
As to combustibility?	Yes	Yes	Yes	Yes	Yes	Yes	Maybe	Yes

*Refer to code sheet at end of table

TABLE A-2 - Properties of foams surveyed (cont)

Generic type	Urethanes							
Supplier	Emerson & Cuming	Foam Systems Co.	Foam Systems Co.	Foam Systems Co.	Fomo Products, Inc.	Freeman Chemical	Hoover Universal	Insta-Foam Products, Inc.
Product identity	Eccofoam FPH-FR	FS 24	FS 25	FS 234	Fomospray	Chempol 30-212/30-2038	RU 6100	FS-75 Kit
Type of foam	Rigid	Rigid	Rigid	Rigid	Semi-rigid	Rigid	Rigid	Rigid
Density, lb/ft^3	3	2	2	2.2	1.5	2	2	1.8
Comp strength, psi*	30	33	25	40	10	25	29	17
Tensile strength, psi*	40	53	40	50	12	40	ND	35
Combustibility, rating*	SE	25	25-30	25	SE	25	< 75	65
, method	D1692	E84	E84	E84	D1692	E84	ND	E84
, smoke	ND	115-500	135-500	200-500	ND	250-350	<250	400
Water absorption, lbs/ft^2*	ND	ND	ND	ND	ND	ND	ND	ND
, %	3	ND	ND	ND	ND	ND	ND	5
Moisture vapor transmission,* perm in	ND	ND	ND	ND	ND	ND	1.7	3
Maximum service temp, °F*	275	ND	ND	ND	ND	ND	ND	250
Commercial use*	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)
Mode of preparation*	Spray	Spray	Spray	Spray	Froth	Spray	Spray	Froth
Equipment costs, $1000	6	6	6	6	None	6	6	None
Stopping cost/100 ft^2, $	60	45	45	45	300	45	45	300
at thickness, in	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Unusual positive properties*	None	None	None	None	(7,8)	None	None	(8)
Unusual negative properties*	(17)	None	None	None	(14,15)	None	None	(14)
Suitable for mine use?	No	Yes	Yes	Yes	No	Yes	No	No
As to mode of production?	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
As to combustibility?	No	Yes	Maybe	Yes	No	Yes	No	No

*Refer to code sheet at end of table

TABLE A-2 - Properties of foams surveyed (cont)

Generic type	Urethanes							
Supplier	Isochem Resins Co.	Olin Corp.	Olin Corp.	Olin Corp.	Polymir	Texas Urethanes	United Foam	United Foam
Product identity	9 R 2	Autofroth 7415-02	Polysystem 7622-02	Polysystem 7613-02	FMS-20	Texthane 220-20	UFC-115	UFC-250
Type of foam	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid
Density, lb/ft^3	2	2.1	2.2	2.2	2.1	2	2	2
Comp strength, psi*	ND	30	27	30	33	27	33	ND
Tensile strength, psi*	ND	40	ND	ND	58	40	47	ND
Combustibility, rating*	SE	20	25	64	20	25	< 75	25
, method	D1692	E84	E84	E84	E84	E84	E84	E84
, smoke	ND	250	200	440	150	175	<450	ND
Water absorption, lbs/ft^2*	ND	ND	ND	ND	ND	ND	ND	ND
, %	0.75	ND	ND	ND	0.04	ND	ND	ND
Moisture vapor transmission,* perm in	ND	ND	ND	ND	ND	2.4	ND	ND
Maximum service temp, °F*	165	ND	ND	ND	ND	ND	ND	ND
Commercial use*	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)
Mode of preparation*	Pour	Froth	Spray	Spray	Spray	Spray	Spray	Spray
Equipment costs, $1000	6	ND	6	6	6	6	6	6
Stopping cost/100 ft^2, $	45	75	45	45	45	45	45	45
at thickness, in	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Unusual positive properties*	None	None	None	None	None	None	None	None
Unusual negative properties*	(14,15)	(19,22)	None	(14)	(22,23)	None	(14)	None
Suitable for mine use?	No	Yes	Yes	No	Yes	Yes	No	Yes
As to mode of production?	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
As to combustibility?	No	Yes	Yes	No	Yes	Yes	No	Yes

*Refer to code sheet at end of table

TABLE A-2 - Properties of foams surveyed (cont)

Generic type	Urethanes							
Supplier	UpJohn Co.	Urethane Systems	Utah Foam Products Co.	Witco Chemical	Witco Chemical	Witco Chemical	Witco Chemical	W. R. Grace
Product identity	Isonate CPR 468	USC 230	FMS 20	SS-0640	SS-0501	SS-0119A/ SS-0120B	SS-0715	Hypol
Type of foam	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid	Semi-rigid
Density, lb/ft^3	2	2	2	2	2	2	2	10-15
Comp strength, psi*	28	25	26	32	30	32	27	ND
Tensile strength, psi*	40	40	52	ND	ND	ND	ND	ND
Combustibility, rating*	25	25	25	25	25	< 75	< 75	< 25
, method	E84	E84	E84	E84	E84	E84	E84	E84
, smoke	350	500	300	450	<450	<450	<450	ND
Water absorption, lbs/ft^2*	ND	ND	ND	ND	ND	ND	ND	ND
, %	ND	2.2	0.08	ND	ND	ND	ND	ND
Moisture vapor transmission,* perm in	ND	ND	1.8	ND	ND	ND	ND	ND
Maximum service temp, °F*	ND	ND	ND	ND	ND	ND	ND	ND
Commercial use*	(4)	(4)	(4)	(4)	(4)	(4)	(4)	ND
Mode of preparation*	Spray	Spray	Spray	Spray	Spray	Spray	Spray	Spray/Pour
Equipment costs, $1000	6	6	6	6	6	6	6	10
Stopping cost/100 ft^2, $	45	45	45	45	45	45	45	115
at thickness, in	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Unusual positive properties*	None	None	None	None	None	None	None	(12)
Unusual negative properties*	(22,23)	None	(22,23)	None	None	None	None	(17)
Suitable for mine use?	Yes	Yes	Yes	Yes	Yes	No	No	Maybe
As to mode of production?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Maybe
As to combustibility?	Yes	Yes	Yes	Yes	Yes	No	No	Yes

*Refer to code sheet at end of table

Code for TABLE A-2

Code

(1)	Cabinets for small equipment, appliances, tooling, etc.
(2)	Packaging or cushioning
(3)	Potting, casting, sealing
(4)	Thermal insulation
(5)	Injection molding or extrusion
(6)	Strong
(7)	1-component system
(8)	Self-contained unit - no equipment needed
(9)	Usable at higher temperatures
(10)	Very low flame spread
(11)	Low smoke evolution
(12)	Can be applied to wet surface
(13)	Foam must be transported into mine and applied with adhesives
(14)	High or unknown flame spread
(15)	Very friable or weak
(16)	Contains fillers which can settle to bottom
(17)	Contains free TDI or formaldehyde
(18)	Short shelf life of components
(19)	3-component system
(20)	Pour-in-place; may need partial mold
(21)	Requires warm substrate
(22)	Data obtained from literature
(23)	Company does not want to participate
ND	No data

Comments on Table 3 Performance Entries

Some of the information shown in Table 3 is discussed below:

a) Combustibility - The general trade policy about combustibility information is to use the best data available. No information usually means that the material will burn rapidly. Data obtained using ASTM Method D1692 (which has been discontinued because of its ambiguity) indicates minimal resistance to fire. The high density foams which are usually molded or extruded are typically rated by the UL94 procedure with VO/5V being the best rating. The UL94 results do not correlate with E84 or E162 data. We would anticipate that only foams having VO/5V ratings have sufficient resistance to fire to be safe for mine use. A UL94 rating can be obtained only from UL (Underwriters Laboratories).*

   Many foam manufacturers had ASTM E84 data on their foams. Sometimes called the 25 ft. or Steiner tunnel test, ASTM E84 is a fairly severe test although its correlation with mine conditions is doubtful. E84 tests are invariably run by independent laboratories only, such as Underwriters Laboratories, Factory Mutual, U.S. Testing, and Southwest Research Institute. Several building codes and insurance underwriters require that foams be "listed" or certified. After initial certification, UL and FM have a policy of periodically checking on the quality and/or composition of the foam. Although the foam may have been "certified" several years ago, it has usually been checked and confirmed during the last year. UL guards its certification marks zealously.

b) Solubility in Water - All the foams listed in Table A-2 are primarily organic in nature. All have very low solubilities in water. In fact, the solubility is so low that it is almost never determined. A few foams contain fillers that are also insoluble in water. Probably none of these foams or their fillers would have sufficient solubility in water to exclude them from mine applications. The leaching tests in this study would identify any foams which would be unsuited for mine use.

c) Toxicity - None of the foams in Table A-2 are themselves toxic. Some raw materials can be hazardous and these should be listed by generic type.

* Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding, and does not imply endorsement by the Bureau of Mines.

(1) Epoxy Foams - Some unreacted epoxides are known to be skin sensitizers on certain people. The catalysts are usually either strong primary amines (vesicants) or boron trifluoride complexes. Their suitability for mine use must be determined for each specific system.

(2) Phenol/formaldehyde and Urea/formaldehyde - The resins may be slightly alkaline, but the catalysts are usually strongly acidic, which might create some problems. Safety and handling procedures will have to be determined for each individual system. Furthermore, formaldehyde vapors can be evolved during foaming.

(3) Isocyanurate and Urethane Foams - These foams all use polymeric isocyanates as one of the main components. The isocyanate TLV is 0.02 ppm. Experience in mines has indicated that the isocyanate vapors react out in 2-3 minutes to form polyureas.

d) Effects of Temperature and Humidity - Only limited data were available. These data concerned water absorption, moisture vapor transmission, and usable temperature range. How this information relates to the suitability of various forms for stoppings is not clear.

e) Application Equipment - Basically, the foams are prepared by (1) molding, (2) extrusion, (3) pouring, (4) frothing, or (5) spraying. Equipment costs for any individual type of foam reflect the degree of sophistication and capacity of the equipment. Molders and extruders are expensive; they run from $50,000 to $250,000 and more. The froth, pour and spray equipment can usually be purchased in the $5,000 to $10,000 range. The cost figures shown in Table 3 are reasonable estimates.

f) Costs of Stoppings - The exact cost of labor and materials for a 100 ft^2 stopping varies with the material and method of application. Most of the raw materials cost from $0.50 to $1.50 per pound; the silicones are in the $4 to $7 per pound range. Labor was estimated at $16 per man-hour. The calculated cost varied from $15 to $540 for a stopping.

The cost figures fell into rather well-defined ranges and these were averaged and used in Table A-2. While these are not exact, the orders of magnitude and the relative costs should remain valid.

Equipment costs are not included except for the 3 foams marketed in self-contained disposable units. Many mines prefer the disposable units because they reduce labor and maintenance costs and delays. It is difficult to quantify these

costs; however the overall costs of using foam from a self-contained unit are about 10 times that of using a typical froth or spray applied foam. Spray equipment is not overly expensive ($8,000), but it must be moved to the site. Moving such equipment requires considerable expense in a mine situation.

While molding machines and extruders are expensive, the mines could probably purchase the foam from a manufacturer just as they do concrete blocks. This procedure would avoid the capital investment and maintenance costs.

g) Positive and Negative Foam Properites - Most of the foams in Table 3 are probably capable of making a stopping. The unusual positive properties are numbers 6 through 12 of the Table 3 code. Numbers 13 through 23 were considered to be unusual negative properties.

h) Suitability for Mine Use - This was decided primarily on the basis of the mode of production and the combustibility of the foams. Being unsatisfactory in either respect makes these unsuitable for mine use.

Foams were listed in Table A-2 as "maybe" when the mode of application, strength of the foam, and/or open-celled structure of the foam might create special problems.